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COMPUTER MAPPING OF COAL RESERVES BY SULFUR LEVEL: STUDY AREA REPORT

LABORATORY FOR COMPUTER GRAPHICS
AND SPATIAL ANALYSIS

Contract No. CPA 70-16
Air Pollution Control Office
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16. Abstracts
The aim was to display the quantity of coal available at various sulfur levels. The study areas were in the Appalachian Coal Region and, in particular, in a two county area in Maryland. Values for sulfur content, bed thickness, and quantity of coal were manipulated and mapped using several computer mapping programs. The problem definition, computer program used, study area selection and data acquisition, and the graphic techniques used are covered. The study areas and data used, and the computer maps produced are discussed in some detail. The step by step description of the mapping procedures used for the study areas, the references, and the technical aspects of program development are presented.

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COMPUTER MAPPING OF COAL RESERVES BY SULFUR LEVEL

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PREFACE

The Air Pollution Control Office (APCO) of the Environmental Protection Agency is interested in ways of displaying the quantity of coal available at various sulfur levels. It was felt that computer mapping of the coal data might provide a relatively quick and inexpensive tool.

Data was provided by the Bureau of Mines for study areas in the Appalachian Coal Region and, in particular, in a two county area in Maryland. Values for sulfur content, bed thickness, and quantity of coal were manipulated and mapped using several computer mapping programs available at the Laboratory for Computer Graphics and Spatial Analysis at the Harvard Graduate School of Design. Although the work was carried out for these study areas, the main emphasis of the project was on providing a tool with general applicability to coal data anywhere in the United States.

The problems of obtaining sufficient reliable data for mapping cannot be emphasized strongly enough. At first glance it would appear that there is a great deal of coal data available. However, when the data are broken down by type, coal seam, and location, there is actually very little useable information available at the present time for all the types of data needed for a study such as this.

It is felt, and has been stressed throughout, that more meaningful results could have been attained if there had been a more equal distribution of data points and a more equal number of analyses taken at these points. All of us were aware that this might be a problem at the outset of the project and our fears have been substantiated. We hope that pointing this out is the kind of constructive criticism that may prove most helpful in overcoming deficiencies in data acquisition so that more meaningful results may be attained in future work.

Of significant importance, however, is the potential applicability of each of the types of maps produced and their usefulness to APCO as adequate data are made available.

The Study Area Report is divided into three main sections, entitled:

I BACKGROUND
II STUDY AREA FINDINGS
III APPENDICES

The first section covers the problem definition, computer program used, study area selection and data acquisition, and the graphic techniques used. The second section discusses the study areas and data used, and the computer maps produced in some detail. The final section contains the step by step description of the mapping procedures used for the study areas, the references, and the technical aspects of program development.

The Study Area Report does not contain any speculative information as to possible future uses of the techniques nor does it include all the computer program manuals and specifications necessary for application of the techniques to other coal data and study areas. These manuals and related information are contained in a companion report on General Documentation.

As stated in the problem definition, the project was designed to demonstrate the capabilities of the SYMAP Computer Mapping Program to display the sulfur levels of coal and the quantities of coal available at various sulfur levels. The types of maps desired and the criteria for selecting study areas for demonstration are discussed.

The requirements and specifications for each of the three computer mapping programs are explained in the next part as well as the necessary output devices and the significant aspects of program development which took place during the project. This technical section serves as an introduction to the use of the program found in Section III (Appendices) and Volume Two.

Study area selections and data acquisition are presented in terms of the preliminary examination of areas and a discussion of the actual study areas chosen: the four-state Appalachian Coal Region, and Allegany and Garrett Counties in Maryland.

The final part of the first section is concerned with graphic techniques, particularly the contour intervals and symbolism used for mapping. The problems of map size, particularly for final reproduction and display, are briefly discussed.

The second section is concerned with the actual study area procedures and findings. The data used for the two study areas is discussed in the first part: (i) the sulfur content data aggregated by counties for the Appalachian Coal Region, (ii) sulfur data aggregated by towns for this area, (iii) sulfur and bed thickness data by mine location for Allegany and Garrett counties in Maryland, and (iv) washability data for Maryland by mine location.

The computer maps produced for each study area and set of data are discussed in some detail, followed by the conclusions and recommendations resulting from the case study areas. The material provides the background for the more detailed mapping technique discussions of Section III (Appendices) and Volume Two: General Documentation.

Section III (Appendices) contains the step by step computer mapping procedures for each study area. It also contains the references used in the project and a discussion of the significant programming developments, including the use of statistical routines, special data handling procedures, and the changes made to the mapping programs for this project.

We would like to acknowledge the invaluable support and advice of Russell Flegal, Project Officer, Office of Program Development, Air Pollution Control Office, Environmental Protection Agency, and S. J. Aresco, Coordinator, Energy Data Bank, Bureau of Mines, U.S. Department of the Interior.

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All unpublished data used in the project were supplied by the Air Pollution Control Office and the Bureau of Mines.

Cambridge, Massachusetts
April 1971

John C. Goodrich
Project Director and Editor

STUDY AREA REPORT

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I. BACKGROUND

1. Problem Definition
2. SYMAP and Related Programs
3. Study Area Selection and Data Acquisition
4. Graphic Techniques

1. PROBLEM DEFINITION

The Air Pollution Control Office (APCO) of the Environmental Protection Agency (EPA) is interested in ways of displaying the quantity of coal available at various sulfur levels. This is in conjunction with efforts to find ways for supplying low-polluting fuels to areas of the country adopting emission control regulations. It was felt that a relatively quick and inexpensive tool such as computer mapping could prove to be useful in the process.

The SYMAP Computer Mapping program of the Laboratory for Computer Graphics and Spatial Analysis enables one to express clearly and visually information that has generally been available only in extremely long and cumbersome lists of tabular data. The Laboratory has demonstrated the unique and valuable applications of the SYMAP and related programs in numerous projects including a demonstration grant running from 1968 to 1970 from APCO (68A-2405D) undertaken to show the application of computer graphics to air pollution analysis and control. It was demonstrated that as more and more air quality data becomes available in computer usable form, a tool such as computer mapping can be very useful as an aid in air pollution studies, particularly for displaying changes in air quality over time.

The scope of work for investigating the computer mapping of coal reserves by sulfur level emphasized several major points. It was hoped that the proposed work would demonstrate the capabilities of SYMAP to display the sulfur levels of coal and the quantities of coal available at various sulfur levels. As a result of the work a new and valuable tool would be provided for the decision-making process which is concerned with locating low sulfur coal for the potential control of air pollution.

Recognizing the need for a tool with general applicability, the program developed was to be demonstrated for a specific area of the country with applicability to coal data anywhere in the United States. The necessary data was to be provided by APCO in cooperation with other Federal agencies, including the US Bureau of Mines, and state and local agencies, including state mining and geological survey departments. Whenever possible this data was to be provided in a computer form compatible with the needs of the SYMAP program.

The study area was to be selected by reviewing available analytical, washability, and geological data for at least three possible areas. The criteria for selecting a study area included:

(i) a reasonable and manageable number of seams, and,

(ii) adaquate availability of data for each seam for sulfur content, seam thickness and extent, and washability.

The area selected was to be as extensive as possible, subject to the above criteria. It was suggested that the output maps be approximately three feet by four feet.

Computer maps were to be prepared for the selected study area showing the following:

--Isolines of sulfur level in percent sulfur by seam, in class intervals suggested to be 0.0 to 0.5 percent, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5, 2.5 to 3.0, 3.0 to 5.0, and greater than 5%;

--Quantities in tons per acre of mineable reserves of raw coal by seam with sulfur contents less than 1%, assuming current mining practice. APCO was to provide the data in a form that would explain the assumed current mining practice to be used. When more than one seam existed in an area, maps were to be made for each seam or several selected seams and a composite summing all of the selected seams 20" or more in thickness was to be made;

--Isolines, as the coal lies in the ground, showing the sulfur level the coal could be washed to at 65% yield by seam. The class intervals of sulfur level were suggested to be 0 to 1%, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 3.0, 3.5 to 5.0 and greater than 5%;

--Quantities in the ground in tons per acre of washed marketable coal of less than 1% sulfur content, assuming, first, the economics of present coal preparation and washing techniques in mining practice, and, second, that the market will take incremental price increases. APCO was to provide the data in a form that would explain the various preparation, washing, and mining techniques to be considered for both the current practice and the incremental price increase cases.

The project was to involve any necessary adapting of the SYMAP techniques and development of the necessary computer programs and analysis to produce these low sulfur coal availability maps. In addition, the feasibility and applicability to APCO's needs of utilizing various three-dimensional graphical techniques in conjunction with the two-dimensional SYMAP portrayal was to be investigated. Finally, the technical report was to include a general discussion of the program, permitting persons to apply the general program to other coal areas, and a discussion of the limitations on the use of the program.

This emphasis on documentation was thought to be very important, particularly because of the lack of data for adequately demonstrating the techniques for the study areas to be examined. Even if no definitive conclusions can be drawn for the study areas, the general applicability of the program to any areas of the country where reasonable data can be made available is a significant contribution in itself.

Data on sulfur content and seam thickness are available for many coal beds in the country. From the data one can determine the quantity of coal presently available at various sulfur levels. Wherever information on washability is obtained, a series of maps can be made which show the quantities of coal that may be obtained at various yields. Decisions can then be made as to what cost should be incurred to supply low sulfur coal to areas needing this type of fuel.

Such a computer mapping approach is important for several reasons:

(i) it can be automatically tied to large scale computer-based data banks, such as exist for coal and related data;

(ii) alternative situations can be postulated and mapped, with comparisons made quickly and inexpensively between the alternatives; and,

(iii) as more and more data on coal reserves, mining practices, and demand requirements are made available, the tool can be immediately refined to give more meaningful and accurate results.

Not all of the objectives of the project could be fully met. We were able to display the sulfur levels of coal for a number of seams at different scales depending upon the study area size. We were also able to display the quantity of coal available for less than 1% sulfur content, but the lack of data prevented us from calculating quantity for the study area with the accuracy hoped for.

The program was demonstrated for specific areas with applicability to coal data anywhere in the United States. However, it is likely that many of the problems of map accuracy and data availability encountered with the study area will be found with other parts of the country in the near future.

The study area selection criteria were somewhat academic in that adequate data were not available for any study area--for all variables concurrently and more than one coal seam. The four-state study area chosen was quite extensive but the scale of the mapping--26" wide maps--resulted in a reduction to 25% of original size for printing in this report and a great deal of lost detail.

The isolines for sulfur content used were almost the same as those initially suggested. However, only a few of these isolines were actually relevant, in many cases.

The washability and market price information had to be re-stated in terms of sulfur content versus the expected yield of coal. This did not significantly affect the results, although the relationship of quantity to cost was thereby eliminated from the analysis.

In general, the computer mapping techniques were demonstrated for the study area, these study areas are representative of data and problems encountered elsewhere, and the techniques can now be applied to other areas of the U.S. where coal data are available, subject to the constraints and accuracy of the required data discussed at length in this report.

2. SYMAP AND RELATED PROGRAMS

Three computer mapping programs were used in this project. The SYMAP program was used for the majority of the maps produced, particularly for maps of sulfur content and bed thickness. The GRID program--which was adapted from SYMAP to specifically handle data input in terms of a regular grid--was used in all cases where maps or data sets were compared, as in determining the quantity of coal at various levels of sulfur content. Finally, in a few cases the SYMVU program was used to display the three-dimensional representation of the same surface shown in two-dimensions with the SYMAP or GRID programs. All three programs were developed principally at the Laboratory for Computer Graphics and Spatial Analysis.

2.1. THE SYMAP PROGRAM

SYMAP generates map displays showing the values of spatially distributed data, according to their actual geographic location on a base map. Combinations of standard computer printout symbols are used to print a scale of tone from black to white which can correspond to a data value range from large to small. Mathematical computations can be performed on the data if necessary before mapping. Options are provided for the rescaling of raw data and for variations in symbolism.

For this project values for sulfur content, bed thickness, and quantity of coals in tons per acre were displayed for each of several coal seams. Uniform scales of symbolism were used so that maps in a series could easily be compared. In many cases mathematical computations were performed prior to mapping, particularly to determine the quantity of coal available for a given sulfur content, given various yields from washing.

The SYMAP program is written in Fortran IV. It can be used on a computer system equivalent to the IBM 360-40, or CDC3600. Computer storage requirements are at least 32,000 words, or 128,000 bytes. Such systems are available in most commercial, government, and university computation centers.

All work on this project was done using Fortran IV on an IBM 360-65 at the Harvard Computing Center. Version 5.15 of the SYMAP program was used which requires 150K bytes of storage. Certain operations--comparing surfaces using a newly-written subroutine for SYMAP--required 200K bytes.

The program can produce conformant, contour, proximal, and dot maps. In conformant maps, predefined areas or zones are filled with the symbol tone assigned to their data values. Contour or isoline maps show the variation of the data over the whole study area; the display is analogous to the contour bands used to show changes of elevation on topographic maps. Proximal maps use the nearest-neighbor principle, with any non-data position being given the value of its nearest data point. They are similar in appearance to conformant maps. The program will also produce dot maps, using a variety of symbols. The maps produced in this study were all of the isoline or contour type. This was because it was felt that the data being mapped--sulfur content, thickness, and quantity--all tend to vary continuously over a coal bed rather than to exhibit fixed values for data zones.

To produce computer maps, a deck of punched cards must be prepared as input to the computer. This deck consists of a number of "packages," each covering a specific category of information. The most basic of these packages, with a brief explanation of their general purpose, are listed below.

The MAP package is always required; use of the other packages is determined by the type of map desired.

The MAP package specifies, below the map, an appropriate title for the identification of each separate map that is to be run. It then instructs the computer to make each map by using certain electives that may be useful. It is not necessary to specify any of these electives since each has a standard default. The availability of these electives is a major feature of the SYMAP program and adds greatly to its flexibility. Some of the electives are:

(i) Size: used to specify the overall dimensions of the rectangular border surrounding the study area on the output map;

(ii) Content: used to specify the portion or extent of the study area (as shown on the source map) to be mapped by the computer; the scale of the map to be produced can be changed, or a portion of the study area may be shown, at any scale.

(iii) Number of Levels: used to specify the number of levels, or class intervals, (up to twelve) into which the total range of the data is to be subdivided for mapping purposes; another elective can be used to specify the value range intervals for these levels;

(iv) Symbolism: used to specify the black-to-white tone symbolism for the levels as well as symbolism for the data point locations, contour lines, and areas outside the study area; and,

(v) **Text:** used to provide supplementary textual information below the map.

The OUTLINE package is used to describe the outline of the study area by specifying the x-y coordinate locations of the outline vertices. For this project the outline was generally the seam outcrop line or the line of 28" bed thickness.

The DATA POINTS package is used to give the positions of the data points to which data are to be related, by specifying their coordinate locations. Data points may be either points for which data are available or centers of areas ("data zones") for which data are available. When warranted by the nature of the study, other "centers" may be used. For this project the data points were the centers of counties or towns for which data on sulfur content were known or the actual or assumed location of mines, mine openings, or core samples.

The LEGENDS or OTOLEGENDS package causes supplementary information to appear on the face of the map by specifying coordinate locations and content. Legends include such things as political boundaries, location names, a scale and north arrow, and the title block. The principal legends used in this project were state and county boundaries, relevant place names, and the scale.

These three packages--OUTLINE, DATA POINTS , and OTOLEGENDS are used (together with a MAP package which is always required) to produce a 'base map' for testing purposes. The base map and consequently these packages generally remain the same for a whole series of maps. Once the base map has been determined and tested it is necessary to relate the appropriate values to the data points--by use of the VALUES package--and select any options desired together with the title with the MAP package.

The VALUES package is used to assign the appropriate values to the data points. In this project this might be the assigning of values for sulfur content averaged for all samples in a county for the seam in question to the centroid of the counties which would be the data point locations. Very often a series of maps is to be run from a large data bank of variables. In this case an extremely flexible user-subroutine is employed in conjunction with the VALUES package to select the values for the particular variable to be mapped. Raw data given to the computer may be related, manipulated, weighted, and aggregated in nearly any manner desired with this subroutine to produce the values for mapping. The subroutine may also be used in conjunction with the other packages, often to transform coordinate locations.

Immediately ahead of the packages of data cards described above, certain introductory cards (as required by the particular computing center being used) will need to be provided--together with a copy of the SYMAP program on cards, tape, or disk.

Producing isopleth maps with a computer program such as SYMAP has numerous advantages over producing maps by hand. First, if one is producing a considerable number of maps computer mapping is a much faster, less expensive, and more accurate means of displaying spatially variable data. For this project and the general application of the techniques used, a considerable number of maps would be produced in a series. The very nature of computer mapping eliminates the drudgery of making a great number of maps by hand.

Second, a wide variety of options are available to the computer map maker that are not possible with maps made by hand. The user of SYMAP can experiment with different symbolism and shading to achieve the desired tones; he can use various contour level intervals to portray different meanings about the data, and he can add or delete political boundaries, rivers and legends by changing only a few cards from map to map. When mapping by hand one cannot afford to make several maps and select only one of them. Because of the time and financial constraints involved, one must often settle for a finished product that is less than satisfactory and may not show the information desired.

Third, the human error often encountered in the associating of values with the appropriate data points is virtually eliminated once the DATA POINTS and VALUES packages have been established and verified to have a 1:1 correspondence. There is no chance of transfering data from a table to the wrong data point on the map as is often the case with mapping by hand. In addition if a data bank is used which contains the data points and all their associated values, errors for the whole series of maps can be eliminated at the outset quickly and efficiently.

Finally, the contouring algorithm in SYMAP avoids the subjective interpolation error so inherent in the decisions of individual hand mappers or cartographers. SYMAP not only standardizes this contouring process but also greatly reduces the painstaking time and energy normally involved.

2.2. THE GRID PROGRAM

The GRID program is a modified version of SYMAP specifically designed for displaying data collected on the basis of geographic grid cells. Each grid cell may be shown on the computer-produced map as a single character or group of characters. Whereas SYMAP accepted information at irregularly spaced data points such as mine locations, and then interpolated values at all points on an assumed surface, the GRID program requires that a value be read in for every grid cell. These values are then displayed directly without interpolation. The GRID program was used in this project to determine quantity of coal at each grid cell mapped (where the sulfur content was less than 1%) based on the previously mapped values for bed thickness interpolated from data points with the SYMAP program. The program was also used to produce composite maps of quantity of coal for more than one bed; here the quantity for each of the beds was summed at each of the grid cell locations.

The program displays its data using a line printer but operates more efficiently and economically because of its special purpose design, which eliminates the need for the relatively expensive interpolation algorithm. For a user who does not need the added flexibility of the SYMAP program, the GRID program can provide substantial savings. The GRID program presently operates on an IBM 360/40.

Version 3 of the program was used for this project. It was run on an IBM 360-65 at the Harvard Computing Center and required 150K bytes of storage.

To obtain a map, the user must provide three sets of instructions and has the option of providing a fourth set. The instructions are prepared in the following packages: Data Package (usually a separate tape), Map Package, Irregular Outlines Package (Optional), and Subroutine Flexin.

The DATA package contains the data which generate the graphic display. It is similar to the VALUES package in SYMAP. The program is written for a maximum of 10,000 grid cells, but the Multiple Data Set Option permits the user to handle unlimited numbers of data cells. For this project approximately 12,000 grid cells were used. These were displayed as single character cells allowing for direct comparability between the SYMAP produced maps and the GRID produced maps derived from them.

The MAP package permits the user to specify the precise form of the map output in terms of various electives. It is similar to the MAP package in SYMAP; many of the electives are specified with exactly the same format.

The IRREGULAR OUTLINE package allows the user to specify the boundaries of the study area when he is not dealing with a grid which is rectangularly bounded. For this project the same outline was specified as was used with the SYMAP program.

No additional package having to do with legends was necessary for this project. A special edited version of the SYMAP program was used to create a data file containing the legends, and an edited version of the GRID program was then used to read the data file. Therefore, the same legends were used with both GRID and SYMAP.

SUBROUTINE FLEXIN is the Fortran subroutine which allows the user to specify the format of the data. It is identical in use to the user subroutine of SYMAP; however, with the GRID program the subroutine must always be used to specify the format for reading in the values. For this project values created by the SYMAP program were read in, compared or manipulated, and resultant values mapped on a cell by cell basis.

2.3. THE SYMVU PROGRAM

The SYMVU program provides the user with oblique views of a given surface.

SYMVU is especially well suited to be run in conjunction with SYMAP or GRID which will generate the necessary matrix values.

Version 1.0 of SYMVU was used for this project. It was run on an IBM 360-65 at the Harvard Computing Center and required 200K bytes of storage. Only a few SYMVUs were run of surfaces mapped with SYMAP and GRID as a demonstration of the applicability of the program.

The user of SYMVU needs to supply a matrix of surface values, and a set of parameters specifying the type of oblique view desired. The basic options available to the user are:

(i) the oblique view may be orthographic or in perspective;

(ii) the viewing angle may be varied in both the vertical (z) direction and horizontal (x, y) plane;

(iii) the lines that SYMVU generates to define the surface of the three-dimensional view may follow down the columns, across the rows, or through the diagonals of the input matrix;

(iv) the size is specified by width and height;

(v) treatment of the non-study area may consist of deleting it, darkening it, or setting it to a value of zero.

2.4. OUTPUT DEVICES

The maps produced by either the SYMAP or GRID program are generated by a standard chain line printer. The printer used for this project was an IBM 1403 at the Harvard Computing Center. The printer is capable of producing 132 characters on a line; at 10 characters per inch, this means a map 13 inches wide, with two characters for the vertical borders. The printer produces eight lines per inch with these mapping programs.

If a map is too large to fit on one sheet of paper, the SYMAP program will subdivide a map into 13 inch sections. Since this is frequently the case, a simple splicing job is required. The GRID program has a similar option for producing as many map sheets as are required; generally each map sheet is associated with a separate data set. With these programs a special carriage control tape is used to assure the proper line spacing for each page; in this way the normal spacing at the top of a page does not occur in the middle of a map. The programs allow one to print up to four over-printed characters to achieve the desired gray scale for mapping.

The three-dimensional views produced by the SYMVU program are generated by a pen plotter. The plotter used for this project was an 11 inch CALCOMP plotter at the Harvard Computing Center. The vertical size of the plot is governed by the height of the paper which is 11 inches; there is no constraint on the length of the plot because the paper is on a continuous spool.

2.5. DEVELOPMENT OF PROGRAMS

The concept, overall design, and mathematical model for the SYMAP program were developed in the autumn of 1963 by Howard T. Fisher, working at Northwestern Technological Institute. Programming was carried out by Mrs. O. G. Benson of the Northwestern University Computing Center. Since that time many others have contributed ideas and cooperated in bringing the program to its present state. Major improvements in the program were made by two Harvard students, Robert A. Russell and Donald S. Shepard, who was responsible for the algorithms on spatial interpolation.

The GRID program was written at the Laboratory for Computer Graphics and Spatial Analysis in 1968 by David Sinton and Carl Steinitz. The SYMVU program was written at the Laboratory in 1967 and 1968 by Frank J. Rens under the direction of Howard T. Fisher. Since then it has undergone major changes and improvements.

Significant programming developments resulting from this project included:

(i) capability to compare surfaces directly using the SYMAP program;

(ii) incorporation of SYMAP-type legend options into the current version of the GRID program; and,

(iii) development of data handling procedures to quickly and inexpensively interface these three programs.

Program development is discussed in detail in Section III (Appendices). In the SYMAP program changes were made in the printout of the textual information below the map. In addition, a new subroutine was written for comparing surfaces having the same study area outline. Since the GRID program can generally be used more efficiently for comparison of surfaces, this SYMAP subroutine is only useful for the user who wishes to perform the comparison with one program and one submission.

The major changes to the GRID program involved the rewriting of the legends routine that had been included in previous versions of the program. This enables the same kind of legends used with the SYMAP program to be displayed on a map produced by GRID. With the inclusion of these changes, the two programs are now completely compatible in terms of graphic output.

A number of other important changes in the mapping procedure were undertaken as part of the program development. These include:

(i) The use of statistical routines to aid in the choosing of the levels or contour intervals for mapping;

(ii) data handling procedures used to facilitate the mapping, particularly when a large series of maps is involved; and,

(iii) the use of a simple program to create legends showing the number of analyses associated with each data point.

3. STUDY AREA SELECTION AND DATA ACQUISITION

The study area for which the computer mapping techniques were to be demonstrated was to be selected after reviewing the available analytical, washability and geological data for at least three possible areas. The criteria for selecting an area for detailed study included: (1) a reasonable and manageable number of seams, and (2) adequate availability of data for each seam for sulfur content, seam thickness and extent, and washability. Subject to these criteria we wished to pick as extensive an area as practicable so as to be able to develop and test large-scale mapping techniques useful to APCO.

The review of possible study areas began with a literature search and was followed by trips to the data bank and computer facilities of the Bureau of Mines, since nearly all of the useful available data is contained in their computerized data banks. The initial review pointed to areas in Clearfield County, Pennsylvania, and Garrett and Allegany Counties in Maryland as providing the best data.

To avoid the use of detailed geological maps at the outset, the computer mapping techniques were first tested for an 84 county four-state area in the Appalachian Coal Region. At this scale readily available data aggregated by towns and counties and uncomplicated estimations of bed outcrop lines can be used to give an overview of the sulfur content of coals in a region. Figure 1 shows this Appalachian Coal Region study area. Phase I of the project involved mapping the sulfur content of reserves by counties; Phase II involved mapping reserves by towns.

The maps produced show that Garrett and Allegany Counties in Maryland have large deposits of low sulfur coal and are worthy of closer examination. This area appeared to have the best data and was chosen as the principal study area for Phase III. Stage One of Phase III involved the mapping of reserves by mines, while Stage Two was concerned with the mapping of the washability data.

The Phase III study area is shown by a square box in Figure 1. A summary of the study areas, coal beds, and data for all these phases of the project is shown in Table I-1.

As expected, the greatest difficulty encountered in the project was the obtaining of adequate data to work with. Sufficient data to produce meaningful results never were available for the detailed study area of Phase III, although this did not significantly detract from the demonstrations of the applicable techniques. The table below shows the relative amounts of time spent on data acquisition, the data handling necessary prior to mapping, the actual testing and perfecting of the mapping techniques, and the analysis of the maps.

The table also shows the percent of time we would expect to spend on each phase if the data were readily available.

	acquisition	handling	mapping	analysis
actual	30	25	30	15
expected	15	15	40	30

In addition the computer base map development and testing takes place at the same time as data acquisition and handling; in this way, the base maps and procedures are all prepared in time for the actual mapping phase.

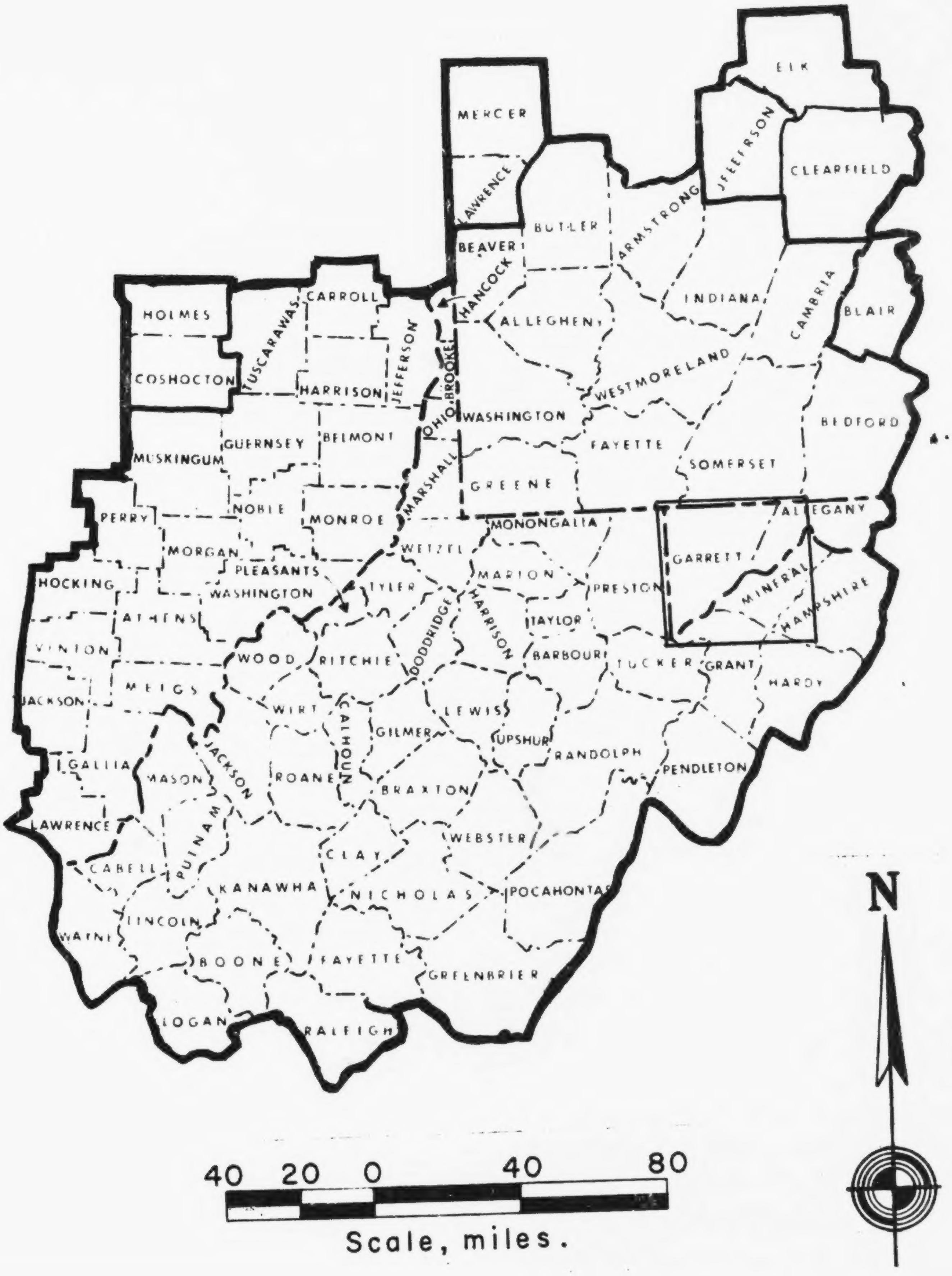


Figure 1
Map of Study Areas

APPALACHIAN COAL REGION	DATA AND BEDS MAPPED		PROJECT NAME
	Sulfur Content	Quantity	
Reserves mapped by counties.	Pittsburgh		Phase I
Reserves mapped by towns	Pittsburgh Middle Kittanning		Phase II
ALLEGANY AND GARRETT COUNTIES			
Reserves mapped by mines	Upper Freeport Upper Bakerstown	Upper Freeport Upper Bakerstown	Phase III - Stage One
Washability data mapped by mines	Upper Freeport	Upper Freeport	Phase III - Stage Two

Table I-1
Study Areas and Data

The apparent delays in data acquisition were a result of (1) data aggregation procedures and technical computer difficulties with the necessary data banks for Phase II and (2) data aggregation procedures and unavailability of data expected from private sources for Phase III. The delays in the data handling aspects in Phase I were due to expected trial and error attempts to mate the data banks with the mapping programs, and in Phase II to the need to determine all data point locations by eye from detailed maps of the region.

In conclusion, much of the time that was devoted to data acquisition, data handling, and the actual mapping for the study areas chosen can be accounted for by the demonstration aspects of the project; however, some of the time spent is related to the nature and availability of data and, thus, will be a factor in applying the techniques to other study areas in the near future. This is particularly true of (1) the washability data, which are available in sufficient quantity for only a few locations and were not yet incorporated into the Bureau of Mines data banks, at the time, (2) data point locations which had to be taken from maps by eye, and (3) geological maps showing bed outcrops which must be pieced together for large areas and are often incomplete for parts of a region.

To successfully use computer mapping as a reliable tool, the problems of data availability and form need to be overcome. The mapping programs will require:

(1) information to easily and inexpensively develop base maps, including bed outcrop maps;

(2) computerized data locations, in addition to the coal data values themselves; and,

(3) sufficient data, by seam, with adequate spacing of data point locations; this is particularly true for the washability data.

The following sections discuss briefly the preliminary examination of areas, the Phase I and II Appalachian Coal Region study area, and the Phase III Allegany and Garrett Counties study area. The actual references for the literature search and data sources, will be found under General References in the Appendices (Section III).

3.1. PRELIMINARY EXAMINATION OF AREAS

At the beginning of the project our literature search concentrated on Clearfield County, Pennsylvania, at the suggestion of APCO. This is a low sulfur coal region worthy of detailed study. Very thorough geological maps and descriptions of the area had been prepared (Edmunds; Crentz et al; Blaylock et al.); however, our investigation revealed that there were not sufficient coal analyses or washability data available for mapping.

The following quotations from a letter from William E. Edmunds, Head Coal Geologist for the Pennsylvania Bureau of Topographic and Geologic Survey, summarize aptly the problems encountered with the Clearfield County data and with data for most areas one might wish to study:

". . .all of the readily available coal analyses for the northern Houtzdale area are included in (the) report. There are, doubtless, many more analyses from that area (as well as almost any other area), but they are widely scattered among private and public sources. At any rate, assembling, verifying and identifying them as to coal seam and geographic location is a very time consuming operation.

"My experience in this sort of study has been that the greatest problem is the acquisition and verification of data. The ratio of time spent to amount of raw data acquired is very high.

"I have no doubt that coal reserves and sulfur content can be mapped out by computer methods, but the stratigraphic relations of the various coals must be well understood and considerable data on thickness and sulfur content available. The stratigraphic relations of the various coals in the northern Houtzdale quadrangle are well in hand, but they happen to display complex splitting of some coal seams into separate coals as well as extensive structural faulting. In addition, I doubt that a sufficient number of sulfur analyses are available.

"We have finished, but not published, the coal geology from a number of adjacent quadrangles to northern Houtzdale, but the same problems of complex geology and little sulfur data exist there as well. In the southeastern quarter of the Houtzdale quadrangle, we have had a number of recent coal analyses made, but we have not completed the geologic map and the stratigraphic and structural complexities are extensive.

"In Washington County (south of Pittsburgh) we have had a number of cooperative studies made by the U. S. Geological Survey, which provide good maps and stratigraphic control in that area. Here again I don't think there are enough sulfur analyses available publicly. However, in this area there are a relatively few large coal-producing companies who, I'm sure have copious records, if they were willing to cooperate.

".... Your greatest difficulty is going to be finding an area where the geology is relatively uncomplicated and sufficient analyses available."

The other area examined in detail through a literature search was Garrett and Allegany Counties in Maryland (Boyd; Crentz and Graser; Snyder and Aresco; Toenges et al). This was also a low sulfur coal region worthy of study. Our investigation revealed the following characteristics that made this region superior to Clearfield County for the purposes of this study:

(1) adequate source maps for geological conditions and base map development;

(2) uncomplicated stratigraphic relationships and a reasonable number of seams for mapping; and,

(3) satisfactory availability of data for sulfur content, bed thickness, and washability, with the prospects of additional washability data from private sources.

Accordingly, this two county area in Maryland was selected for the detailed study of Phase III.

Instead of examining a third region before selecting the study area, the large-scale four state coal region was selected for preliminary investigation in Phases I and II. This was done because: (1) our initial investigations did not reveal a third area with the possibility of providing adequate data at this time, although washability data are presently being gathered and made available for numerous areas, and (2) we wanted to begin testing the techniques for a study area without waiting for the availability of detailed geological information for base maps and coal data for mapping. The four state Appalachian Coal Region afforded us such an opportunity.

We investigated the form and extent of the data as well as its general availability. Since it was apparent at the outset that nearly all of the relevant data were available through the Bureau of Mines, our initial review included discussions with people in the Bureau in College Park, Maryland, and Denver, Colorado, involved directly with the coal data banks. We found that for whatever region we selected we could obtain data on sulfur content for raw or clean (washed) samples by county, town, or mine for each coal seam. We could also obtain data for the number of analyses taken at a mine, or for a town or county as a whole. This form determined the data banks for sulfur content used in the project:

Phase I: low, mode, high values by counties;
Phase II: low, mode, high values by towns;
Phase III; low, mode, high values by mines.

The Bureau of Mines data banks also contained information on reserves and bed thickness by counties and in some cases by mine; however, these data were incomplete, particularly on the sub-county level. The data banks did not contain any information on location according to a coordinate system nor on washability data, although both are presently being incorporated into the data banks. It was, therefore apparent that locations would have to be taken directly from maps by eye and that we would be dependent upon published and unpublished reports for the washability data.

We had originally hoped that all data could be provided in a computer-useable form. Therefore, it was necessary to (1) directly acquire and assemble as much information as possible on data locations and washability, and (2) translate this information into a computer-useable form. In some cases this was extremely time consuming; in other cases, sufficient data could never be acquired. In all cases the relevant information is being incorporated into the data banks in computer-useable form.

3.2. APPALACHIAN COAL REGION

The Phase I and II study area was defined by the boundaries of counties in the Bureau of Mines data banks which (1) had data on the sulfur content of coal and (2) were in the area referred to as the Appalachian Region. This study area includes parts of Ohio, Pennsylvania, Maryland, and West Virginia and is shown in Figure 1. Two coal seams were chosen for mapping, based on their extent, number of analyses, and variation in sulfur content: the Pittsburgh and the Middle Kittanning.

A base map was developed showing the seam outcrop lines and legends such as state and county boundaries. The Report of Investigation Series published by the Bureau of Mines shows seam outcrop lines and mined out areas for each coal bed by county. We had anticipated using this series to develop the base maps for the Pittsburgh and Middle Kittanning beds. Unfortunately, the reports had been published for only some of the counties (13 out of 33 for the Pittsburgh Bed) and, therefore, this approach could not be used to obtain a complete base map.

A map of the Pittsburgh Bed outcrop as of 1938 was available from the Bureau of Mines. This map was used in conjunction with the Report of Investigations series to develop the base map for the Pittsburgh Bed; this same base map was used for both Phase I (mapping by counties) and Phase II (mapping by towns).

Similar source maps are not available for the Middle Kittanning bed or for most other coal seams; this 1938 Pittsburgh map had been produced for a specific application. To map a large scale area such as the four state region, one presently has recourse to two approaches:

(1) Determining the outcrop lines from a series of smaller scale U.S. or state geological survey maps; this is very time consuming, a good knowledge of the geology is necessary, and the maps are not always available for every portion of the region. This method was not used.

(2) Defining the study area by the location of data points rather than by the outcrop lines; for some of the mapping in Phase II, the study area was defined by those locations within five miles (or ten miles) of each data point or town. Unfortunately, it is not possible with such an approach to know the true extent of a coal seam, and, therefore, of a low sulfur coal deposit. The base map preparation is easier and large scale mapping is possible without the tedious coding of an outline from the geological maps. In Phase II both the Pittsburgh and Middle Kittanning Beds were mapped by this method.

The Phase I data was obtained for the Pittsburgh Bed from The Bureau of Mines in a form compatible with our computer programs. This included a computer card deck of the values for the number of analyses, low, mode, and high values of sulfur content for each county for both raw and washed samples. It did not include the data point locations which were determined by a manual procedure described in Section III (Appendices).

For both the Pittsburgh and the Middle Kittanning Beds data similar to that of Phase I--the number of analyses, low, mode, and, high values of sulfur content for raw and washed samples--were available by mine for Phase II. The data could not be mapped mine by mine as originally received for one reason: no data was readily available as to the location of the mines in terms of a geographic coordinate system. For the actual mapping, it was necessary to determine the location of each town on a map by eye. The data point locations are presently being made a part of the computer data banks.

These data can be aggregated from mines to towns by a Bureau of Mines computer program. Due to technical difficulties that would have resulted in delays, the data were aggregated by hand; for other study areas, however, it is important to note that the data can be automatically aggregated using a relatively simple computer program.

Portions of the four state region were selected for mapping at a more detailed scale. These included the Phase III study area of Allegany and Garrett Counties, and the northern and northeastern portions of the Appalachian Coal Region, abundant in both data point locations and low sulfur coal. The accuracy obtained by using town data versus county data was also compared. No additional data were necessary for these sub-area studies; they were conducted to demonstrate the flexibility of the mapping program to select and map areas of particular interest at any scale.

3.3. ALLEGANY AND GARRETT COUNTIES

Allegany and Garrett Counties were selected as the Phase III study area, based on the availability of data. Stage One of this work was similar to Phases I and II: mapping of sulfur content for low, mode, and high values by mines. The Upper Freeport and Upper Bakerstown Coal beds were chosen for mapping based on the availability of data and source maps showing the seam outcrop lines.

The data values were provided in the same form as the Phase I and II data. The data points had to be located on the source maps and extracted from field reports; this was done in conjunction with Bureau of Mines personnel and would have been very time consuming if more data points had been involved. We had expected the washability data to be limited, but the sulfur data was also sparse. This is due to the number of seams in the area: when the data is assigned to the appropriate seams, individual seams often do not have enough data points for useful mapping.

Information published by the State of Maryland (1967 annual report) was used to determine the bed thickness for these two coal beds; the Bureau of Mines provided the location for each of the points where thickness had been measured. The availability of similar data and its extent for other areas would significantly affect the use of the mapping programs to determine the quantity of coal (reserves) for a region.

The base maps showing outcrop lines and areas over 28" thick were developed using two sources (Boyd; 1953 Garrett County map; 1965 Allegany County map) as described in Section III (Appendices). Together, these sources contained sufficient information to adequately determine outlines, but similar reports may be available for only a few regions.

Stage Two of this work was concerned with the washability data and the quantities of coal that might be made available under various mining and economic assumptions. Our greatest difficulties with the data were encountered here, as had been expected. Data were incomplete with regard to float and sink analysis for coals of various top sizes. Of some 15 possible seams with data only the Upper Freeport Bed had sufficient washability data and adequate sulfur content, thickness, and base map information for mapping. The results are, therefore, purely demonstrable and cannot be taken literally in terms of quantities of coal available under differing assumptions.

The data from government sources was to have been supplemented with information from private sources, but this was not possible within the time-frame of the project. Private sources will need to provide much of the necessary data in the future.

The washability data was provided in a form such that a minimal amount of data handling was necessary prior to mapping. This data included the associated x and y coordinates which greatly facilitated the coding procedure. The location of the data points for the washability data (and the Stage One data points) determined the study area for Stage Two. This study area is the central portion of Allegany and Garrett Counties as shown in Figure G-1.

Data handling prior to mapping generated values for both total sulfur content and pyritic sulfur content, given different yields from washing with several screen sizes. The sulfur content that could be attained through washing is the total sulfur content, less all or part of the pyritic sulfur, since the pyritic sulfur is easier to remove than organic. We do not know what percent of the pyritic sulfur can be removed; therefore, both the total sulfur content and the total less all pyritic sulfur were mapped to represent the two extreme assumptions. The quantities of coal that could be made available at different yields were determined accordingly.

It is difficult to draw any statistically sound conclusions or inferences on account of the insufficient washability data. However, this lack of data did not prevent the demonstration of the relevant computer mapping techniques. Likewise, the particular study areas may not be representative of the country as a whole but they can adequately demonstrate the scales of analysis useful to APCO.

4. GRAPHIC TECHNIQUES

With the exception of class levels, or value range intervals, the map symbolism is the only and, therefore the most important graphic way to portray the meaning of the data. The value of a map may be easily lost or destroyed by a poor choice of symbolism.

In SYMAP this choice of symbolism is usually made by the program; there is a prestored set of symbolism for up to 12 levels. For this project it was felt that this set of symbolism was inadequate because (1) there was not enough differentiation between some of the levels, and (2) the darkness of adjacent levels seemed to be reversed in some cases. Therefore, a unique set of symbolism was devised.

It is fairly easy to create distinctive symbolism for up to 5 levels. Numerous studies into human tone perception conclude that the eye can discern no more than 7 different shades of gray. Above 7 shades differentiation may be difficult. Since SYMAP's symbolism is derived from over-printed characters, each tone is unique in make-up; therefore, if it is difficult to discern the relative darkness of two adjacent tones, the makeup of the symbolism can show which was intended to be the darker. This is not possible in a hand-rendered map which uses standard dot screen patterns.

The final choice of symbolism was arrived at by considering what had been used before and by experimenting with a number of test maps.

4.1. GENERAL SYMBOLISM CONSIDERATIONS

Given any symbol, its appearance would seem to be a function of several factors: the amount or percent of the cell area darkened or blackened, the amount of white space between characters (external white space), the amount of white space within the characters (internal white space), the intensity or blackness of a character, and the texture and grain of the symbol.

In most cases, the symbols used on a map should be non-directional; highly directional symbols like I and / should be avoided except when emphasis is desired. There are also some symbols which are ambiguous; they may be intensely black, yet have a high percentage of external white space. As a consequence they are both dark and light and do not occupy any position on the grey scale. Examples are symbols like: ⧫ = + 0 I. The circle or "0" is also troublesome since the external white space is minimal, but there is a great deal of internal white space. For this reason, it may be wise to use "0" only when overprinted with some symbol which reduces the internal white space.

The approach to symbolism which seems most successful is to begin with a basic symbol and vary it. As a consequence there is a logical progression created from symbol to symbol. The symbol not only becomes darker, but more complex as well. For example,

- = ≢ ⊕ ■, or,

+ ⨯ ⋇ ▩ ■, or,

○ ⊖ ▩ ▩ ■.

There is often a temptation to dismiss symbols for adjacent levels which are not readily distinguishable, but it should be remembered that in a 10 level map, level 7 is similar to level 6, and some similarity between the symbols is desirable. For most maps the levels represent quantitative variations of a single variable--and this should be apparent visually through the symbolism. A different approach to symbolism is required when, for example, level 1 represents dairy farming and level 2 represents vegetable raising. In this case, the symbols should be descriptive rather than evaluative. This is often the case with conformant or proximal maps.

It would seem that one of the most important considerations should be that the units on the visual scale correspond to the quantitative units on the data distribution. For example, if the value range is divided into five equal levels, the symbols should be chosen so that the grey scale is divided by 5 equal intervals. Carrying this to its logical conclusion means that when the data is skewed and it is necessary to manipulate the levels so that all the observations will not fall in one level, the symbolism should be adjusted appropriately. Eliminating the skewed distribution by assigning an equal number of observations to each level is often unwise, since the skew of the distribution is a fact which should be represented. The unevenness of the distribution may be the most important thing about the map.

There are limits to how precisely this can be done, but there is no doubt that it can and should be done in some cases, where use of equal interval symbolism would be grossly misleading. There are enough easily distinguishable symbols and textures to maintain distinctions between levels and still skew the symbolism.

It may also be desirable to manipulate the symbolism in other ways. For instance, suppose one is concerned with distinguishing between 3 of 10 levels. It might be desirable to use highly distinctive symbolism for these three areas in order to emphasize their locations. The manipulation of the symbolism must be left to the judgement of the individual, but a fair amount of effort should be expended to relate the data to the symbolism. Because of the limited number of levels, it is often necessary to assign a wide value range to one value interval which may reduce the precision of the map. To avoid this, great care should be exercised when dealing with variables which can be controlled. The map will not be effective if it does not represent visually what the histogram bar and the data say it represents.

4.2. SYMBOLISM USED IN THE PROJECT

Many varieties of symbolism are available to the user; the principal objective in selecting symbolism is the readability and graphic tone. Experiments and tests were made on the mapping for all phases and a consistent symbolism developed for use throughout the whole project.

As discussed in the Appendices (Section III) under use of Statistical Routines, an equal interval value range was used for most of the maps produced. It had nine graphic levels as well as a low and a high value symbolism for data exceeding the specified minimum and maximum values. Therefore, the task became one of determining the appropriate level breakdown for each of the types of computer maps and applying the standard symbolism to this breakdown.

The range and distribution of values from the experimental runs for Phases I and II were reviewed and the decision made to map the sulfur content to the nearest 1/2%, with a maximum of 5% and a minimum of 0.5%. Symbolism was also assigned to the few values that might exceed the maximum and likewise to those areas that were below the minimum. The same level breakdown was used for the sulfur content data in Phase III. The symbolism used as coded in the F-MAP package is shown in Table III-12 of the Appendices (Section III).

For Phase II 'critical level' breakdowns were also used to emphasize the isolines of 0.5% and 1% sulfur content. Special symbolism was used for Base Maps in all three phases and for the surface comparison in Phase II. Table I-2 summarizes the use of symbolism for the different map series and Table I-3 shows the various symbolism used.

In Phase III maps were produced for bed thickness and quantity of coal in addition to sulfur content. The level breakdown for bed thickness was 4" per level. After reviewing the minimum, maximum, and distribution of thickness values it was apparent that areas greater than or less than 28" thick were of particular interest. Therefore, level adjustments were made that reflected this 28" value; the minimum value set was 16" and the maximum 52".

Preliminary review of the values for quantity of coal indicated that a value range of 500 tons per acre seemed appropriate to use as the level breakdown. The minimum was set at 5000 tons per acre and the maximum at 9500 tons per acre, with special symbolism assigned for values exceeding the maximum or minimum values.

MAP SERIES	Standard Levels	Critical Levels	Base Maps
Appalachian Coal Region			
A. Phase I - Pittsburgh	X		X
B. Phase II - Pittsburgh	X	X	X
C. Phase II - Middle Kittanning	X		X
D. Phase II - Detail	X		
Allegany and Garrett Counties			
E. Stage One - Reserves	X		X
F. Stage One - Thickness/Quantity	X		
G. Stage Two - Washability	X		X
H. Stage Two - Quantity	X		

NOTE: The Special Symbolism was used for the surface comparison of maps D-1 and D-2.

Table I-2
Levels Used for Each Map Series

```
PERCENTAGE CF TOTAL ABSCLUTE VALUE RANGE APPLYING TO EACH LEVEL

               11.11     11.11     11.11     11.11     11.11     11.11     11.11     11.11     11.11

FREQUENCY DISTRIBUTION CF DATA PCINT VALUES IN EACH LEVEL
 LEVEL         1         2         3         4         5         6         7         8         9
          ===========================================================================================
          ......... --------- ========= +++++++++ ********* XXXXXXXXX XXXXXXXXX █████████ █████████
          ......... --------- ========= +++++++++ ********* XXXXXXXXX XXXXXXXXX █████████ █████████
 SYMBOLS  ....1.... ----2---- ====3==== ++++4++++ ****5**** XXXX6XXXX XXXX7XXXX ████8████ ████9████
          ......... --------- ========= +++++++++ ********* XXXXXXXXX XXXXXXXXX █████████ █████████
          ......... --------- ========= +++++++++ ********* XXXXXXXXX XXXXXXXXX █████████ █████████
          ===========================================================================================
```

A. Standard Symbolism: nine levels, plus high and low levels. (the low is the same as level 1; the high is shown below)

```
PERCENTAGE CF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             100.00

FREQUENCY DISTRIBUTION OF DATA PCINT VALUES IN EACH LEVEL
 LEVEL         1         H
          =====================
          XXXXXXXXX █████████
          XXXXXXXXX █████████
 SYMBCLS  XXXX1XXXX ████H████
          XXXXXXXXX █████████
          XXXXXXXXX █████████
          =====================
```

B. Critical Levels Symbolism: one level, plus high and low levels. (low shows less than 0.5% sulfur coal; high shows 1% or higher)

Table I-3
Symbolism Used for Mapping

```
PERCENTAGE CF TCTAL ABSCLUTE VALUE RANGE APPLYING TC EACH LEVEL

          1CC.CO

FREQUENCY DISTRIBUTICN OF CATA PCINT VALUES IN EACH LEVEL          1
 LEVEL         1                                              ===========
           ===========
            .........
SYMBOLS     .........                                              █
            ....█....
            .........
            .........                                         ===========
           ===========
```

C. Base Map Symbolism: one level.
(two of the three symbols used on base maps; the third substitutes 'pluses' for the 'dots'.)

```
PERCENTAGE CF TCTAL ABSCLLTE VALUE RANGE APPLYING TO EACH LEVEL

              25.00     2C.CC     1C.00     20.0C     25.00

FRECUENCY CISTRIBUTICN CF CATA PCINT VALUES IN EACH LEVEL
 LEVEL        L         1         2         3         4         5         H
         ===========================================================================
          █████████ XXXXXXXXX +++++++++ ......... +++++++++ XXXXXXXXX █████████
          ██2██████ XXXXXXXXX +++++++++ ......... +++++++++ XXXXXXXXX █████████
SYMBCLS   ████H████ XXXX3XXXX ++++2++++ ....1.... ++++2++++ XXXX3XXXX ████H████
          █████████ XXXXXXXXX +++++++++ ......... +++++++++ XXXXXXXXX █████████
          █████████ XXXXXXXXX +++++++++ ......... +++++++++ XXXXXXXXX █████████
         ===========================================================================
```

D. Special Symbolism used for Surface Comparison: five levels, plus low and high levels.
(the greater the difference in the two surfaces, the darker the symbolism)

Table I-3
(Cont'd)

Significantly different level breakdowns were used for Stage Two--washability data--of Phase III for, sulfur content, quantity, and surface comparison. In all cases, however, the standard nine level symbolism was used. All of the level breakdowns used for the project are summarized below:

Map Series	Data	No. of Levels	Value Range	Minimum	Maximum
B	Sulfur content	1	0.5%	0.5%	1.0%
A B C D	Sulfur content	9	0.5%	0.5%	5.0%
D	Surface comparison	5	varies	-1.0%	+1.0%
E	Sulfur content	9	0.5%	0.5%	5.0%
F	Thickness	9	4"	16"	52"
F	Quantity of reserves	9	500 tons/ acre	5000	9500
G	Total sulfur content	9	0.10%	0.60%	1.50%
G	Total less pyritic	9	0.05%	0.45%	0.90%
G	Comparison of mesh size	9	(equal)	0.00%	0.20%
H	Quantity of washed coal	9	(equal)	900	3300
H	Difference in quantity	9	(equal)	(966.43)	(1340.80)

The sulfur content maps in Stage Two used different level breakdowns for total sulfur content, total less pyritic sulfur, and the comparison of sulfur content for different screen sizes; all of these used equal interval value ranges. The quantity of washed coal was mapped with a value range of approximately 266.67 tons per acre in each level. For the comparison of quantity at 60% and 100% yield the actual extremes of the data were used as the minimum and maximum.

4.3. REPRODUCTION CONSIDERATIONS

All but two of the final maps produced in Phases I and II were 26" wide, and these two plus all of the maps in Phase III were 13" wide. The maps were photographically reduced for publication in this report. The 26" maps were reduced to 25% of their original size and printed one to a page; the 13" maps were reduced to 30% of their original size and printed two to a page. Previous studies had demonstrated that such size reductions gave visually good results.

However, photographic reduction of the maps has certain difficulties. In particular the legends may become illegible and the textual and statistical material printed below the map may lose much of its usefulness. Moreover, the tone discernability of the symbolism is somewhat reduced in almost direct proportion to the amount the maps were photographically reduced. But, it is still felt that a relatively good quality can be attributed to the symbolism.

Some of the problems can be overcome by photographing the legends and explanatory information at another scale. In fact, this was done with the titles shown at the bottom of each page; these were separately photographed and stripped into the negatives before printing.

The best solution is to experiment at the beginning of a project to determine the optimum combination of study area size, reduction scale, and legend and explanatory information detail to use in the final presentation or publication of the maps.

II. STUDY AREA FINDINGS

1. Discussion of Study Areas and Data Used
2. Discussion of Graphics
3. Conclusions and Recommendations

1. DISCUSSION OF STUDY AREAS AND DATA USED

The Appendices (Section III) describe step by step the mapping procedures for both the four state Appalachian Coal Region and Allegany and Garrett Counties in Maryland. This section summarizes the information on study areas, data, and procedures, provides an introduction to the discussion of the graphics, and sets forth conclusions and recommendations.

The studies were made at two scales: the Pittsburgh coal was mapped for a large four-state region and, the Freeport and Bakerstown coal were more intensively mapped for a small region in Maryland. Both the regions studied lie within the Appalachian Mountains where Paleozoic beds have been folded into regular parallel anticlines and synclines, tending northeast-southwest. The width of the folds is from four to five miles.

The coal seams are concentrated in rocks of Pennsylvanian age; the Pennsylvanian in Garrett County is about 1,700 feet thick (Amsden, 1953). The coals are concentrated in the synclines in Garrett and Allegany Counties since the Pennsylvanian rocks overlying the anticlines have been stripped off by erosion.

1.1. APPALACHIAN COAL REGION - PHASE I

A four-state area in the heart of the Appalachian coal region was delineated on the basis of available county data. This area is worthy of study because of:

1. the size and extent of the coal seams,

2. the existence of maps showing the extent of some of the seams,

3. the amount of data already collected and in computer-useable form,

4. and the high potential this coal region might have in solving some of the problems of air pollution.

This area is abundant in low sulfur bituminous coal. The total area of the region comprises 293,439 square miles, of which 33,369 square miles is laden with Pittsburgh coal (11.4% of the total study area). Almost 82% of the coal (27,279 square miles) lies in a single pie-wedge shaped seam which is centered near the S.W. corner of Pennsylvania. The remainder of the coal is located in 65 outlying seams over the four state area.

Only maps for the Pittsburgh seam were created, since insufficient information was available to produce a study area outline for the Middle Kittanning seam outcrop. The outcrop used for the Pittsburgh seam was the 1938 strippable reserves, and not the deep reserves. The Phase I base map, including the seam outcrop, was made with a great deal of detail so that particular sections could be 'blown up' for closer examination in Phase II. It was felt that this feature of the technique would have special usefulness to APCO and the Bureau of Mines. Each seam mapped requires a detailed outline of 500-1000 points to achieve this accuracy at the enlarged scale.

The data points representing counties had to be located on the source maps by eye. The rationale behind the placement of the county data points was as follows: (1) If a map from the Report of Investigation series was available, the data point was located in the center of a coal deposit 28" or greater; (2) If no map was found, the data point was located in the "center of gravity" of the seam for that county, based on the 1938 Pittsburgh seam map.

The data bank of values was provided in a computer-useable form by the Bureau of Mines. Each card of the data bank represented a county's information; on this card were the following variables: state, county, and bed codes, the mode, low, and high values and the number of analyses for the sulfur content of raw samples, and, finally, on 19 of the 33 Pittsburgh Bed cards, the mode, low, and high values and the number of analyses for the sulfur content of cleaned (or washed) samples.

The original data bank was manipulated so as to (1) separate the Pittsburgh and Middle Kittanning data, (2) create separate decks for the raw and washed values, and (3) store the variables in the order useful for analysis and mapping, as shown in Tables III-2 and III-4 of Section III (Appendices). This order was: the number of analyses, low, mode, and high values, bed code, state and county code, and state and county name. This exemplifies the type of straight-forward data manipulation that can be performed--either by hand or computer, depending upon the amount of data--to set up the data banks in a convenient form for mapping.

1.2. APPALACHIAN COAL REGION - PHASE II

Phase II dealt with the same four-state coal region, but on a more detailed level of analysis. Whereas Phase I measured the variation in sulfur levels from one county to another, Phase II dealt primarily with variations between towns within these counties.

Much of the base map and data handling work for Phase II was done in conjunction with Phase I; the main additional base map work of Phase II involved determining the x and y coordinates for the towns for both the Pittsburgh and Middle Kittanning Beds, as described in Section III (Appendices). The Bureau of Mines data by mines were aggregated to towns in Phase II because: (1) many of the mine locations were not yet referenced to the grid coordinates, and (2) such small-scale mapping would create a great number of superimposed data points that would cancel out the accuracy obtained at the mine level. At the town level there were 8 superimposed points at 4 locations for the Pittsburgh Bed and 2 at 1 location for the Middle Kittanning Bed for the raw samples; the effective number of data points (considering superimposition) is shown in Table II-1.

It was also necessary to aggregate the data from mines to towns according to the procedures discussed in section III (Appendices). Three data banks of values and associated data point locations were created: (1) Pittsburgh number of analyses, low, mode, and high sulfur content for raw samples, (2) Pittsburgh data for washed samples, and (3) Middle Kittanning data for raw samples; with only 15 data points the washed Middle Kittanning data was not mapped.

APPALACHIAN COAL REGION

Phase I - Counties	Raw Sulfur Content		Washed Sulfur Content	
	(points mapped)	(effective locations)	(points mapped)	(effective locations)
Pittsburgh Bed	33	33	19	19
Phase II - Towns				
Pittsburgh Bed	203	199	56	56
Middle Kittanning Bed	90	89		

ALLEGANY AND GARRETT COUNTIES

Phase III - Mines	Raw Sulfur Content		Bed Thickness		Washability	
	(points)	(effective)	(points)	(effective)	(points)	(effective)
Upper Freeport Bed	20	19	7	7	5	5
Upper Bakerstown Bed	7	6	16	16		

Table II-1
Data Banks Used

The Pittsburgh data was mapped using the same equal value range intervals as Phase I; maps were also produced using the critical isolines and symbolism discussed in the section on Graphic Techniques. A set of maps for the Pittsburgh raw data was produced using five mile and ten mile search radii (or circles of symbolism) about each data point to define the study area, rather than the outcrop lines. This same technique was then used with the Middle Kittanning data since no outcrop line was readily available for this bed. Although no reliable information as to extent of the coal seam can be obtained from such maps, the accuracy around each data point is relatively equal.

The final set of maps run in Phase II utilized previously mentioned data. This included surface comparisons between the mode values of sulfur content mapped by towns versus that mapped by counties. The mode values for raw samples were mapped at several scales for different portions of the study area, including the Allegany and Garrett Counties region of Phase III.

1.3. ALLEGANY AND GARRETT COUNTIES - PHASE III, STAGE ONE

The general purpose of Phase III was to develop and test techniques for determining the quantity of coal in the ground (depending upon sulfur content) and the quantity of coal that could be made available through washing, assuming various mining practices and market economics. The Stage One work was concerned only with calculating the reserves; Stage Two involved the data on washability.

The study area for Stage One was approximately 1000 square miles and included all of Garrett County and the Western one-fourth of Allegany County. Preliminary investigation of available data pertaining to the three categories of sulfur content, thickness, and washability for each of the coal seams that exists within the two county study region led us to the conclusion that the Upper Freeport and Upper Bakerstown seams were the most feasible for our studies. The other seams in the study area presented difficulties due to either an insufficient number of data points, superimposition of data points, or a lack of data in one or more of the three above catagories. Table II-1 shows the data banks actually used, while Table II-2 summarizes the available information for 15 seams in the study region.

In the case of the sulfur content data mapped in Stage One, superimposition of data points reduced the effective number of locations for 4 beds, particularly for the Pittsburgh and Sewickley Beds. Superimposition also affected the number of data points for the washability information of Stage Two, but it did not affect the seam thickness data for the Upper Bakerstown and Upper Freeport Beds.

Bed Name	Code	Counties		Base Map		Sulfur Content		Washability	
		Allegany	Garrett	Maryland	Boyd	Original	Effective	Original	Effective
Waynesburg	023	X			X	2	2	2	2
Sewickley (Tyson)	029	X			X	15	9	2	2
Pittsburgh	036	X	X		X	16	10	1	1
Little Pittsburgh	038	X			X	2	2	1	1
Barton (Elk Lick)	055	X		X	X	4	4	2	2
Upper Bakerstown	062	X	X		X	7	6	-	-
Lower Bakerstown	063		X		X	2	2	2	1
Upper Freeport	071		X	X	X	18	17	6	5
Lower Freeport	074	X	X		X	2	2	1	1
Upper Kittanning	076	X		X	X	1	1	1	1
Lower Kittanning	084		X		X	3	3	3	2
Clarion	087		X			2	2	-	-

Harlem				X				1	1
Franklin								6	3
Redstone								2	2

NOTE: Bed Thickness Data consisted of 16 data points (original and effective) for the Upper Bakerstown Bed and 7 for the Upper Freeport.

Table II-2
Summary of Data Available for Phase III

The base maps for Stage One and Two were the same with the exception of data point locations. Geological maps for Allegany and Garrett Counties were used, as well as a less detailed set of maps from a consultant's report (Boyd, 1964). The map for Allegany county showed few outcrops. The geological map for Garrett County was used as a base since it had outcrop lines for the Brush Creek, Barton, Harlem and Freeport beds. The maps were developed with a great deal of detail so as to extract small areas for closer analysis. Unfortunately, the data contained almost no points for the Brush Creek, Barton, or Harlem beds for either the sulfur or washability data. Consequently, the Upper Freeport base map was the only one which used this source map.

The maps from the Boyd report had to be enlarged to determine the seam outcrop for the Allegany County portion of the study area, and for all of the Bakerstown base map. The Freeport, Bakerstown, Sewickly (Tyson), and Pittsburgh seams were the only ones with sufficient data points for mapping of the sulfur level data. Sufficient data points for washability and thickness were available for only the Freeport bed. The Pittsburgh and Sewickley base maps were not developed because it was felt that no additional information would be obtained from mapping these two beds; all of the procedures and techniques could be tested with the Upper Freeport and Upper Bakerstown coal seams. Base maps for areas over 28" thick were also developed from the Boyd reports.

The sulfur content data for Phase III were made available in two parts: (1) data bank of values, and (2) data point locations. The values, as usual, were available in a computer useable form, similar to Phases I and II. Due to the timing, the data point locations were derived from field notations in Bureau of Mines' reports-- "One mile west of town X"--or by assigning the mine location to the nearest town when more precise locations were unavailable. Twelve beds had data for raw samples; 8 of these had 4 or less data point locations each. The greatest number of locations for washed samples was 6 for the Upper Freeport Bed, and all others had 1 to 2 locations; consequently, the washed samples were not used.

The bed thickness data were also made available in two parts: (1) data bank of values from the state of Maryland 1967 annual report, and (2) the data point locations from the Bureau of Mines. These data were obtained specifically for the Upper Bakerstown and Upper Freeport beds after it had been determined that only these two would be mapped; consequently, the relative availability of data for other seams is not known.

In addition to sulfur content and bed thickness, the quantity of less than 1% sulfur coal was determined and mapped for the Upper Bakerstown and Upper Freeport Coal Beds. Quantity was determined as follows: if the sulfur content was less than 1% for any character location on the map, then the quantity would be calculated and mapped as a function of the bed thickness at that location. The algorithm for determining quantity from thickness was obtained from the Bureau of Mines and is discussed in Section III (Appendices); it assumes that there are 1676 tons of coal per acre-foot.

Composite sulfur content and quantity maps were also made for the Upper Freeport and Upper Bakerstown Beds.

1.4. ALLEGANY AND GARRETT COUNTIES - PHASE III, STAGE TWO

The central portion of the two-county area was selected for further mapping and analysis because of the availability of washability data for the Upper Freeport Bed. The area is approximately 500 square miles. The maps for both Stage One and Stage Two were made at a smaller size then those in Phase I and Phase II. After reviewing several test maps showing the Upper Freeport total outcrop at the Phase I size, it was determined that the information could better be provided at a much reduced map size. This decision was based on the following:

(1) The number of data points was relatively small for sulfur content, thickness, and washability information; it became quite apparent that, because of the small number of data points, the larger maps did not show any more information than did maps made at the reduced scale.

(2) Because of the large amount of testing and experimental work that had to be done, it is easier to quickly evaluate the results from the smaller maps; this avoids the extra time and effort to splice together the several panels or sections that would result if the larger maps were made.

(3) The larger maps in general incur higher computing and printing costs, nearly proportional to the area of the map. The final Stage One maps were printed at a scale of approximately one inch = three miles, and the Stage Two maps at a scale of approximately one inch = two miles.

All of the data used in Stage Two were contained in one small data bank for the Upper Freeport Bed. This included the x and y locations for the 5 washability sampling points used

(1 of the original 6 was in the top, rather than the bottom, bench of the bed and was therefore removed). The washability data were composed of values for total sulfur content and pyritic sulfur content for different yields and top sizes (3/8", 1 1/2", etc).

The first task was to determine the yields to be mapped, in light of current mining practices and incremental price increases at the market. The criteria were translated into 50%, 60%, 70%, and 80% yields as being representative of the problem, with the 60% yield being the one of primary interest.

The second task was to determine the appropriate sulfur content for these yields, given the sampled and derived relationships from the Bureau of Mines. Figure 2 shows the sample plot for the fifth mine listed in Table III-18, (Appendices) for the 3/8" mesh data shown at the top of the table. The values for 50%, 60%, and 70% yield had been statistically derived by the Bureau of Mines, but the values for 80% were interpolated from the plot. Similar plots were done for the other 4 mines for the 3/8" top size, and for all 5 mines for the 1 1/2" top size.

From this set of washability data and the sulfur content and thickness data of Stage One, four types of maps were run in Stage Two:

(1) sulfur content of washed data, by yield and top size;

(2) comparison of sulfur content from 3/8" versus 1 1/2" top size;

(3) quantity of less than 1% sulfur coal assuming washing, by yield and top size; and,

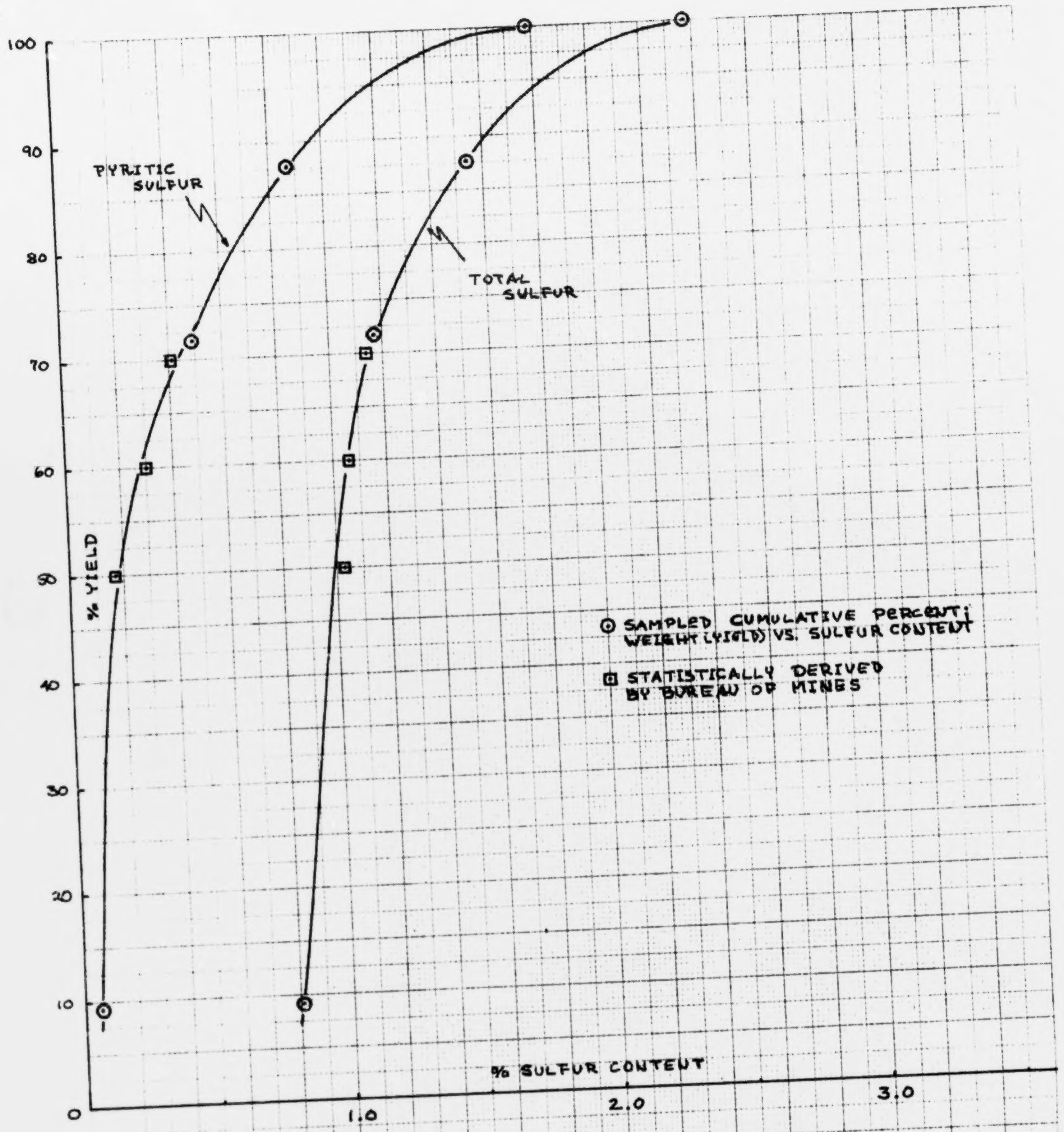


Figure 2

Sample Plot of Sulfur Content Versus Yield

(4) comparison of the quantity of mineable reserves and washed marketable coal at 60% yield.

In most cases, both total sulfur and total less pyritic sulfur were mapped, for the total outcrop and for the areas over 28" thick for the Upper Freeport Bed.

2. DISCUSSION OF GRAPHICS

The following sections contain a detailed discussion of all the graphics produced; the maps themselves are at the end of each section and Tables II-3 and II-4 summarize all of the maps produced in each phase or stage of the project.

We strongly caution the reader about the lack of reliable data and the commensurate unreliability of many of the maps. Perhaps the best safeguard against making any false inferences is to look at a map in one hand and at the base map which shows the data points and the number of analyses in the other hand. In this way, one is made aware of the number of analyses attributed to a data point and the validity one can infer about any given area of the map.

It is felt, and has been stressed throughout, that more meaningful results could have been attained if there had been a more equal distribution of data points and a more equal number of analyses taken at these points. All of us were aware that this might be a problem at the outset of the project and our fears have been substantiated. We hope that pointing this out is the kind of constructive criticism that may prove most helpful in overcoming deficiencies in data acquisition so that more meaningful results may be attained in future work.

Of significant importance, however, is the potential applicability of each of the types of maps produced and their usefulness as adequate data are made available.

2.1. SUMMARY OF PHASES I AND II

Examination of the graphics produced in Phases I and II has shown that there is a definite need for: (1) a more equal number of analyses at each sampling location and (2) a more evenly distributed pattern of sampling locations. The latter problem is especially acute in Phase II while the former problem pertains to both phases.

In Phase I, values were assigned to data points which occur in the center of gravity of seams of 28" thickness within a county. These points represent an area, and, therefore, the data points themselves have no real locational meaning. As a result, any contour maps made from such data point locations can at best give only an impression of the sulfur concentrations. They cannot be interpreted literally, even at the data points themselves. This is in contrast to the maps made in Phase III where the data points are positioned as accurately as possible at the actual sampling locations on the map. Contour maps made in Phase III are at least accurate at the data points themselves.

The maps with county data points (Phase I) had a fairly even spread of data, while the town data point maps (Phase II) had a very uneven spread of data. The county maps could have used quite a few more data points; the town maps could have used many more data points, especially in the center of the main seam. Therefore, of the two sets of maps, Phase I is of reasonable accuracy throughout, while Phase II is of fairly good accuracy along the northern and eastern edges of the Pittsburgh Bed outcrop line but of very poor accuracy in the center.

The use of a limiting search radius around the data points for both the Pittsburgh and Middle Kittanning Beds increased the accuracy of the areas mapped; however, comprehension of the extent of the coal seams for varying sulfur levels was lost. This can be overcome by using outlines and legends in combination--one to show the outcrop line, or extent, and the other to show the areas of nearly equal accuracy, as defined by the search radius.

FOUR STATE APPALACHIAN COAL REGION

		+----Bed Outcrop			-----------+	+-----Search Radius	----------+	
		Washed		Raw		5 mi. radius-Raw-10 mi. radius		
	County	[Levels]	[Critical]	[Levels]	[Critical]	[Levels]	[Levels]	
PITTSBURGH	#analyses	A-1		A-5				PHASE I
	low	A-2		A-6				
	mode	A-3		A-7				
	high	A-4		A-8				
	Towns							
	#analyses	B-1		B-8		B-15		PHASE II
	low	B-2	B-5	B-9	B-12	B-16	B-19	
	mode	B-3	B-6	B-10	B-13	B-17	B-20	
	high	B-4	B-7	B-11	B-14	B-18	B-21	
MIDDLE KITTANNING	Towns							
	#analyses					C-1		
	low					C-2	C-5	
	mode					C-3	C-6	
	high					C-4	C-7	
PITTSBURGH	Difference							
	mode	D-1		D-2				
	Detail of Towns (mode)							
	Allegany and Garrett			D-3--------	D-3			
	Northern			D-4		D-6		
	Northeastern Blow up			D-5		D-7		

Table II-3
Phase I and II Maps

2.2. MAP SERIES A

Map series A contains all of the maps produced in Phase I. Figures A-1 and A-5 show the base maps for the Pittsburgh Bed, including the data point locations (washed and raw respectively) and the number of analyses assigned to each county. The spread of data points is quite even throughout for both sets of data, but there are significant disparities in the number of analyses used for calculating the values at each data point. This is particularly relevant when examining the maps for the low, mode, and high values for each county (Figures A-2 thru A-4 for washed and A-6 thru A-8 for raw samples). All six surfaces show a definite trend from high sulfur coal in the southwest (up to 5.0%) to low sulfur coal (less than 1%) in the northeast and in Allegany and Garrett Counties in Maryland.

2.3. MAP SERIES B

Map series B contains the maps produced in Phase II for the Pittsburgh bed. Figures B-1 and B-8 show the base maps, including the data point locations (washed and raw respectively) and the number of analyses assigned to each town. The data points are not evenly spread out for either set of data. There is a large central area in south-western Pennsylvania that has few data points; this reduces the accuracy in this area. When the base maps are run at this scale, some of the data points and legends showing the number of analyses are lost under the state boundary legends or under other data points. Eight data points are actually superimposed and are shown by a "/" rather than a black square. Figure B-8 contains a box showing the study area for the Phase III analysis of coal in Allegany and Garrett Counties.

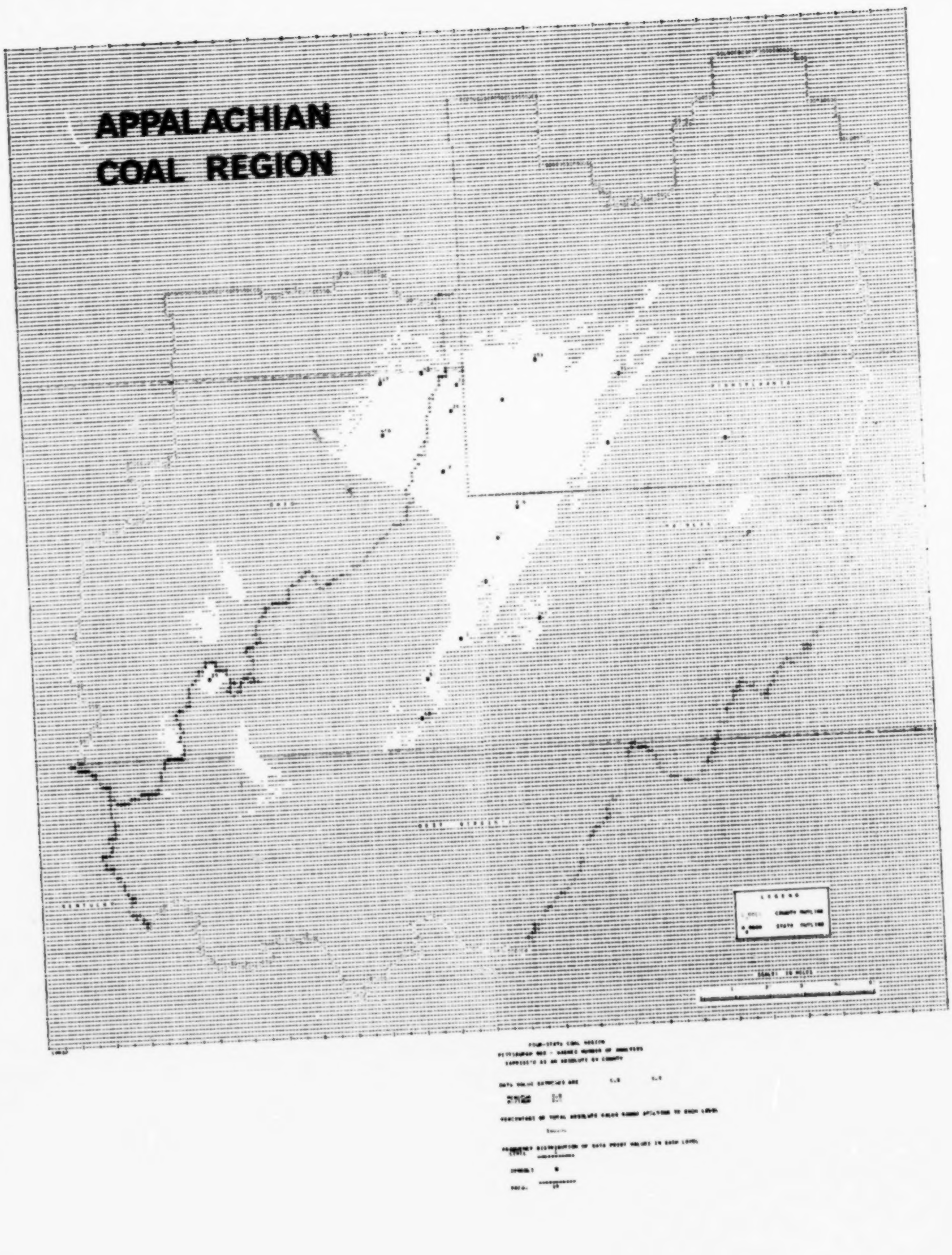


Figure A-1
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Number of Analyses for Washed Samples
Base Map

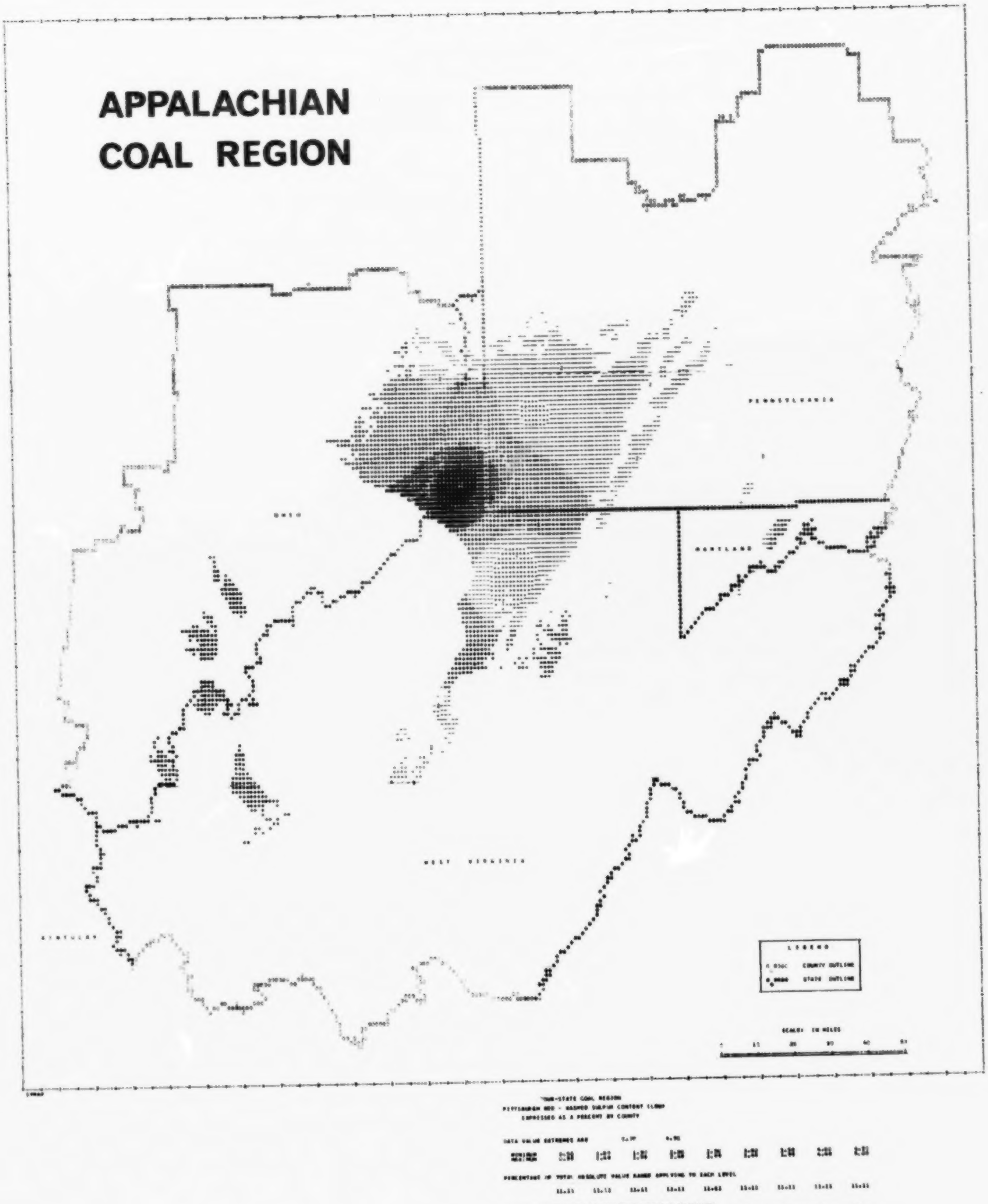


Figure A-2
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Low Values for Washed Samples
(0.5% isoline interval)

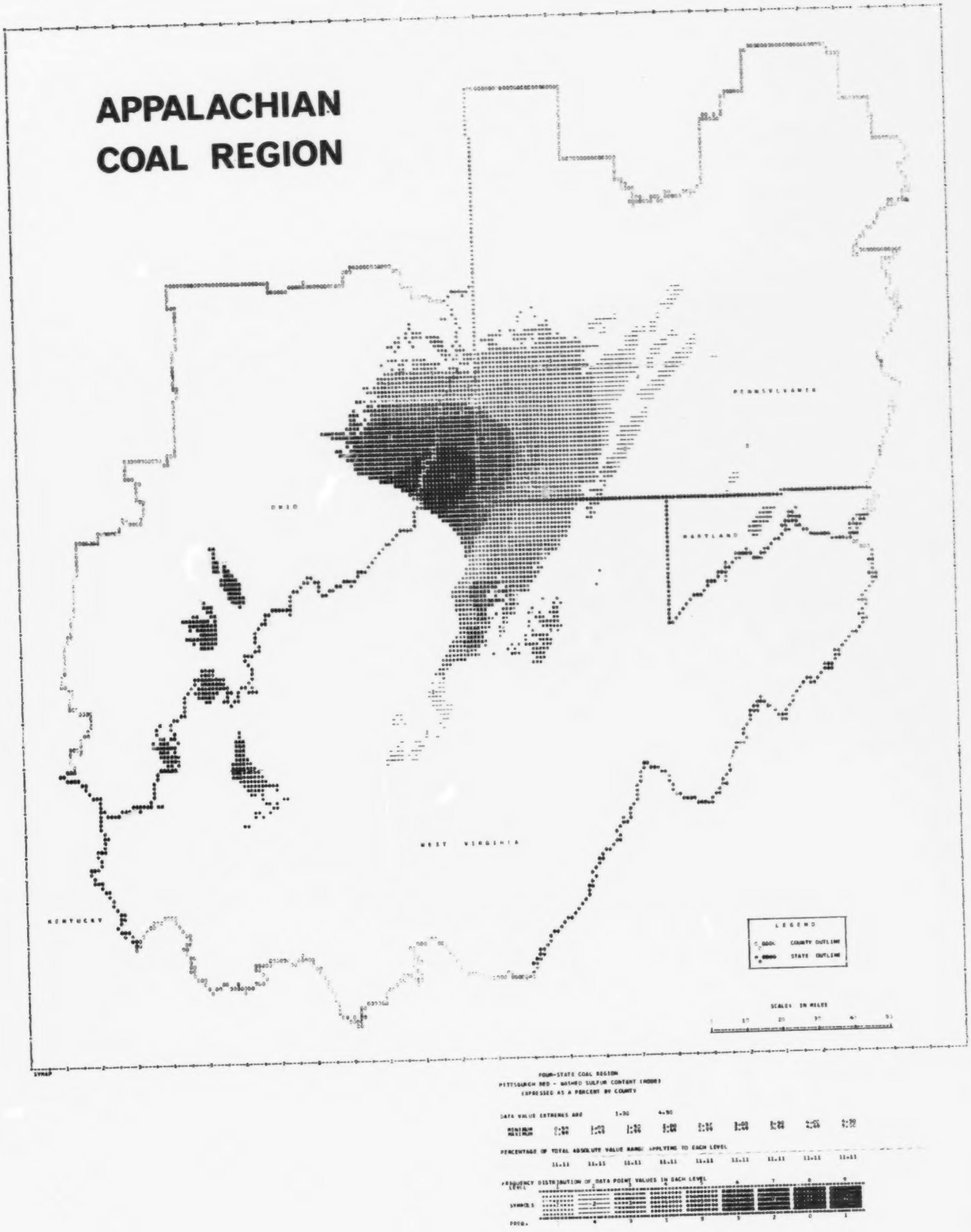


Figure A-3
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Mode for Washed Samples
(0.5% isoline interval)

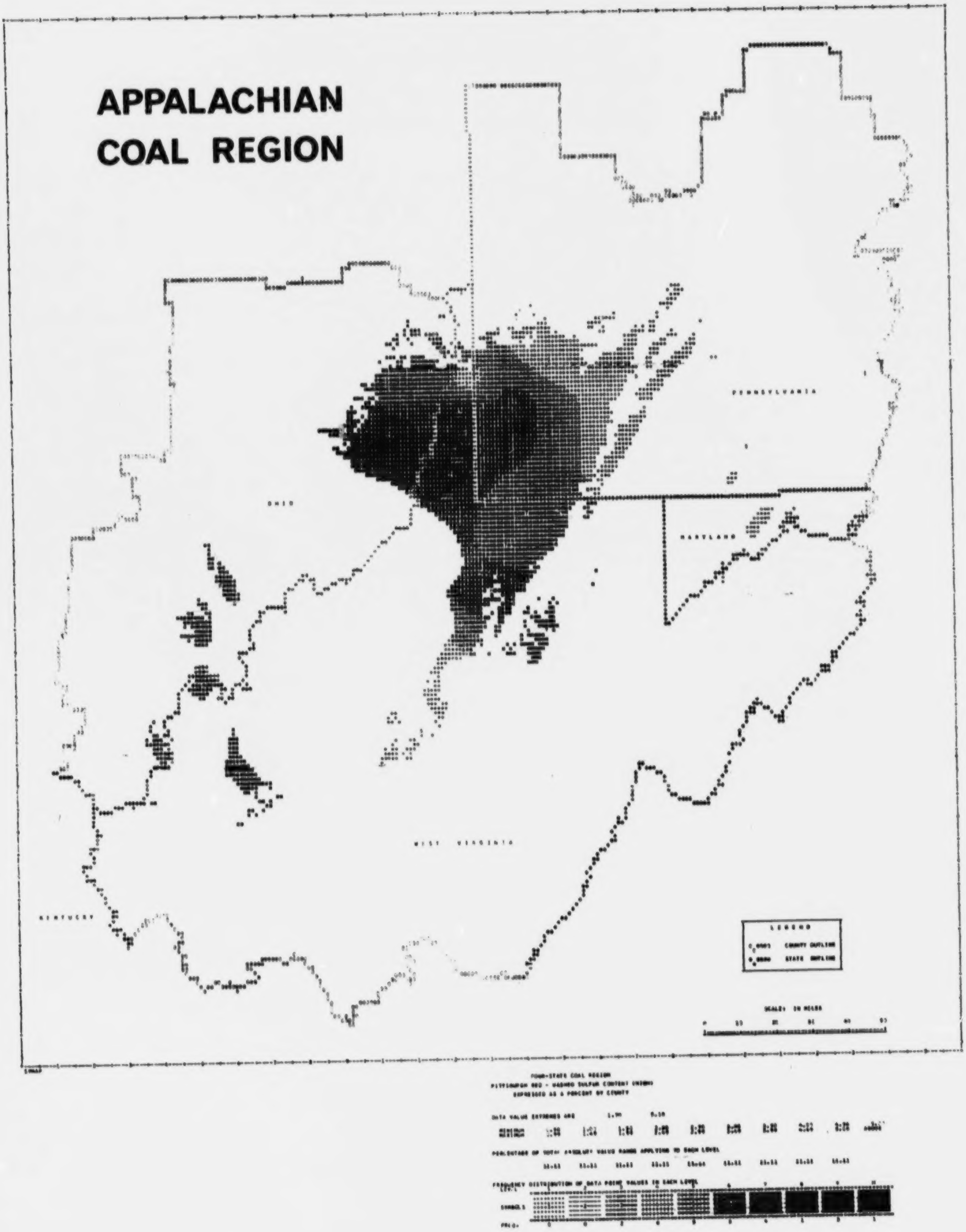
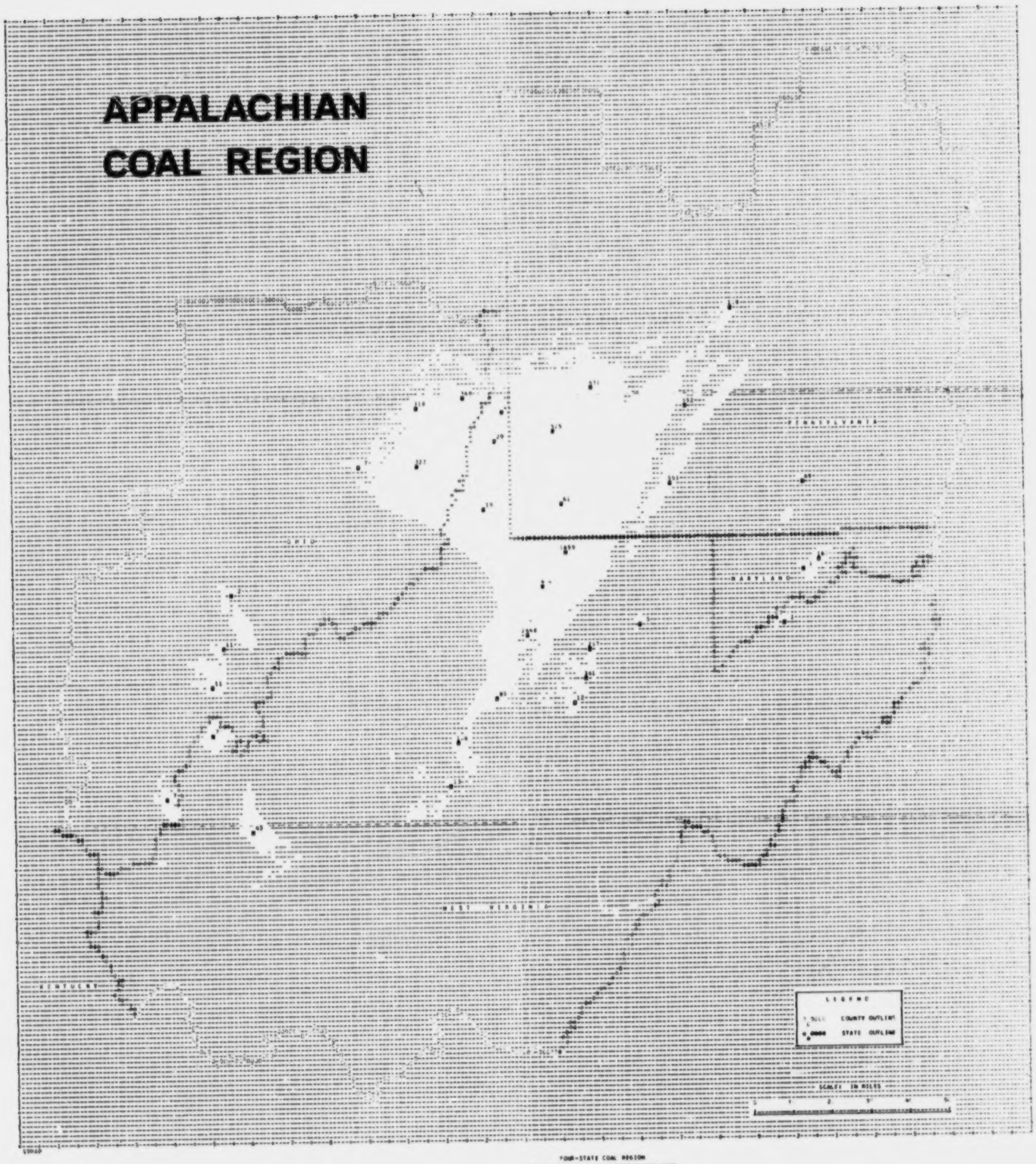


Figure A-4
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
High Values for Washed Samples
(0.5% isoline interval)



```
        FOUR-STATE COAL REGION
PITTSBURGH BED - RAW NUMBER OF ANALYSES
  EXPRESSED AS AN ABSOLUTE BY COUNTY

DATA VALUE EXTREMES ARE        [illegible]      [illegible]

  MINIMUM      [illegible]
  MAXIMUM

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1
            -----------

  SYMBOLS       ●

  FREQ.     -----------
                33
```

Figure A-5
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Number of Analyses for Raw Samples
Base Map

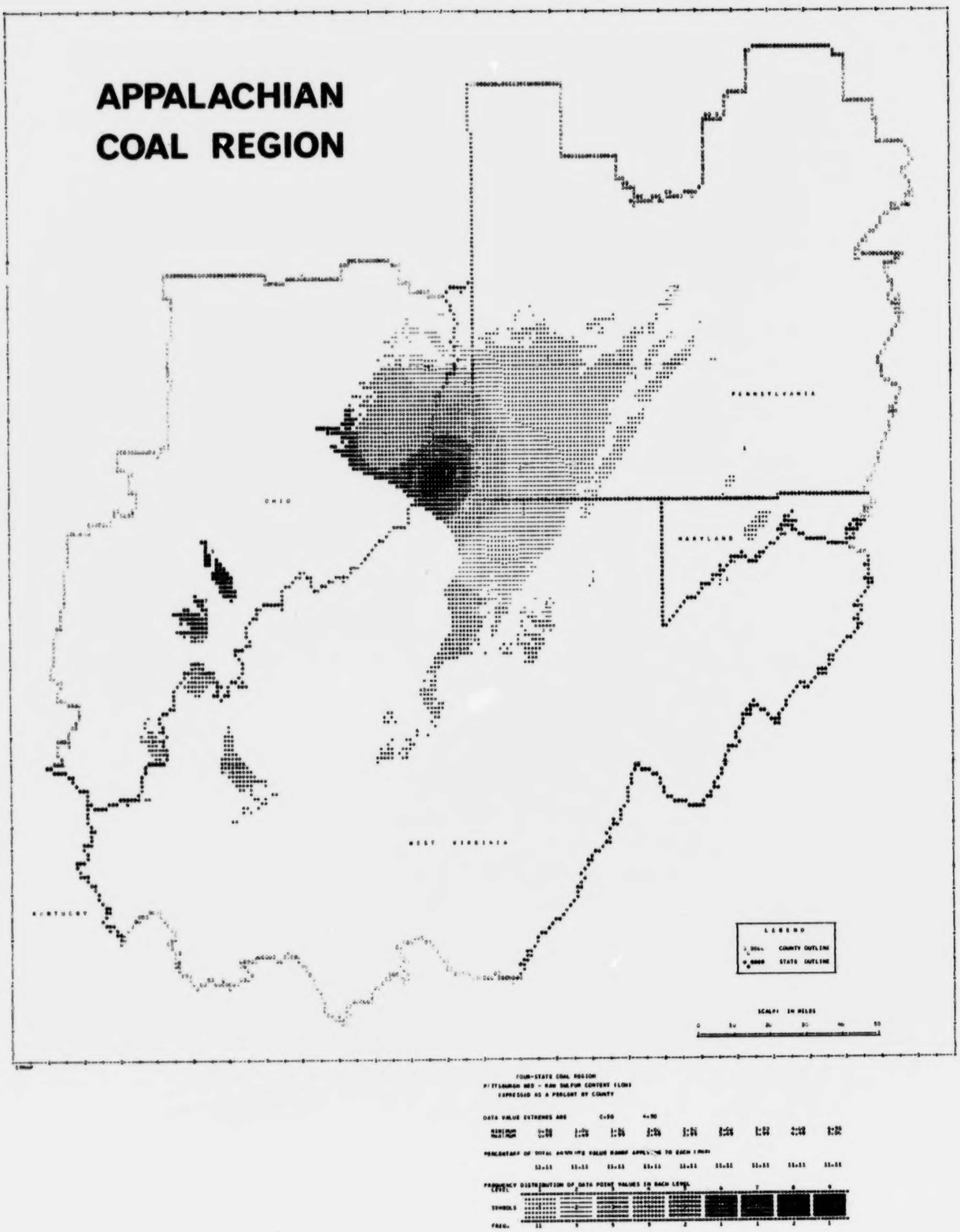


Figure A-6
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Low Values for Raw Samples
(0.5% isoline interval)

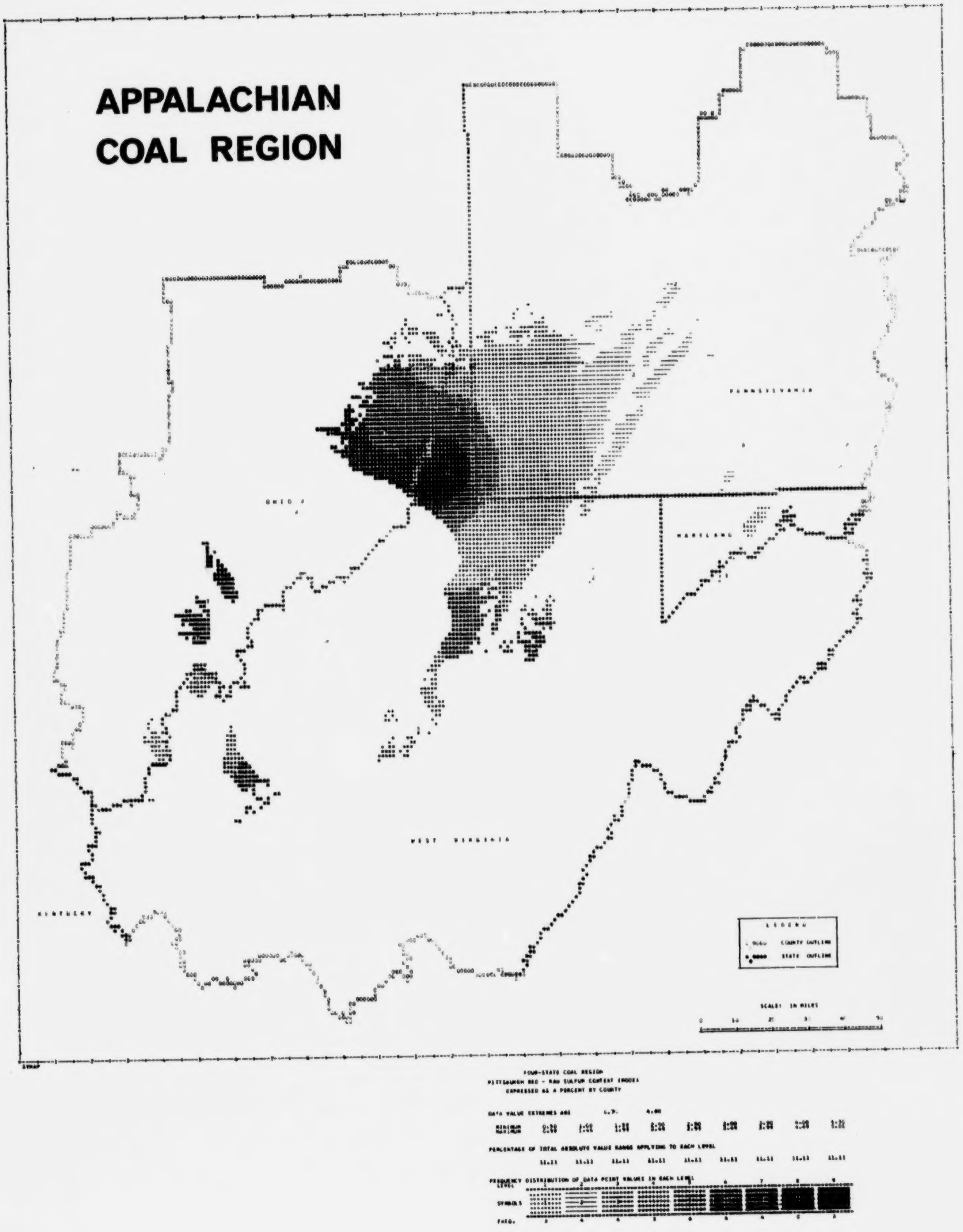


Figure A-7
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
Mode Values for Raw Samples
(0.5% isoline interval)

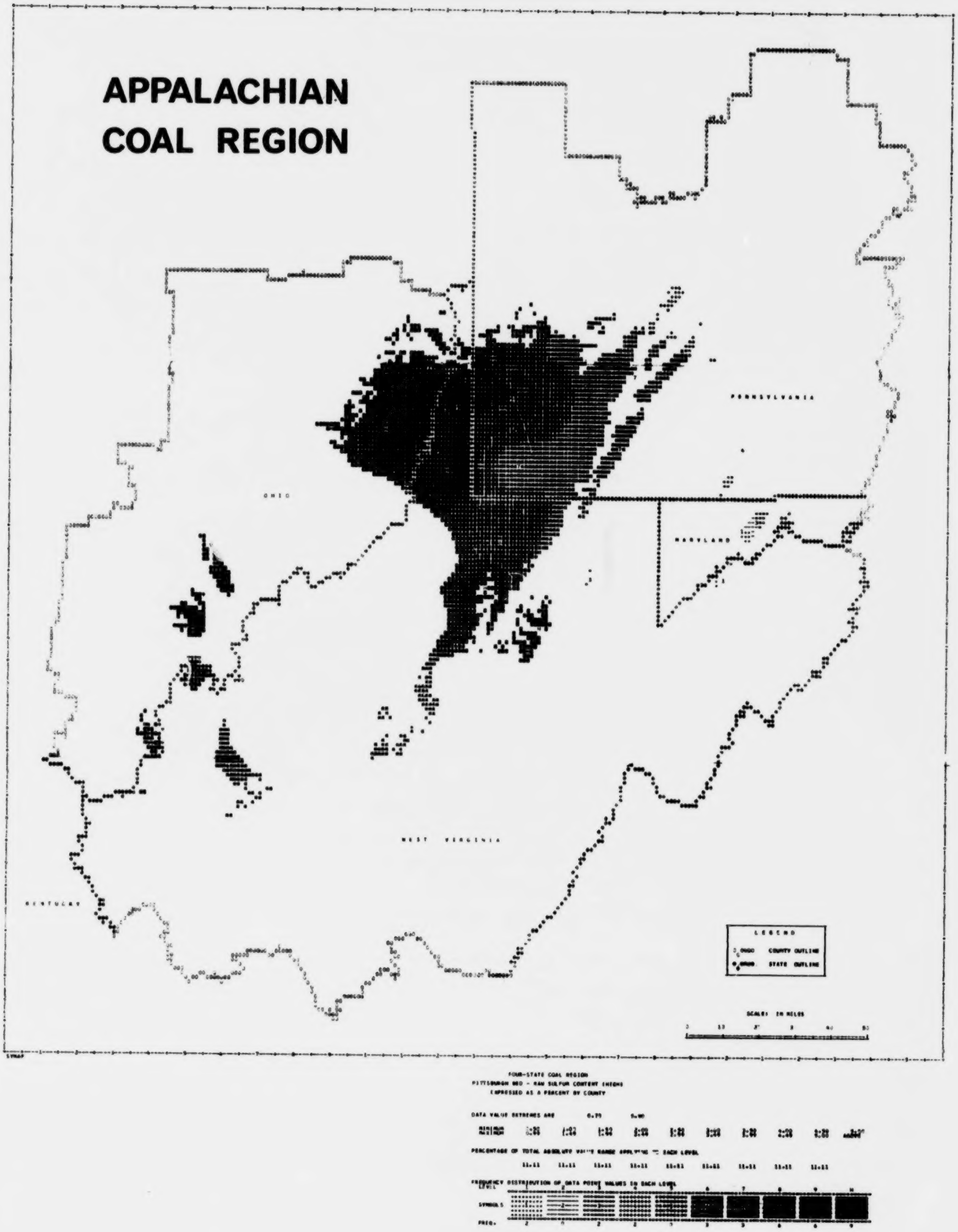


Figure A-8
Pittsburgh Coal Bed
Sulfur Content Mapped by Counties
High Values for Raw Samples
(0.5% isoline interval)

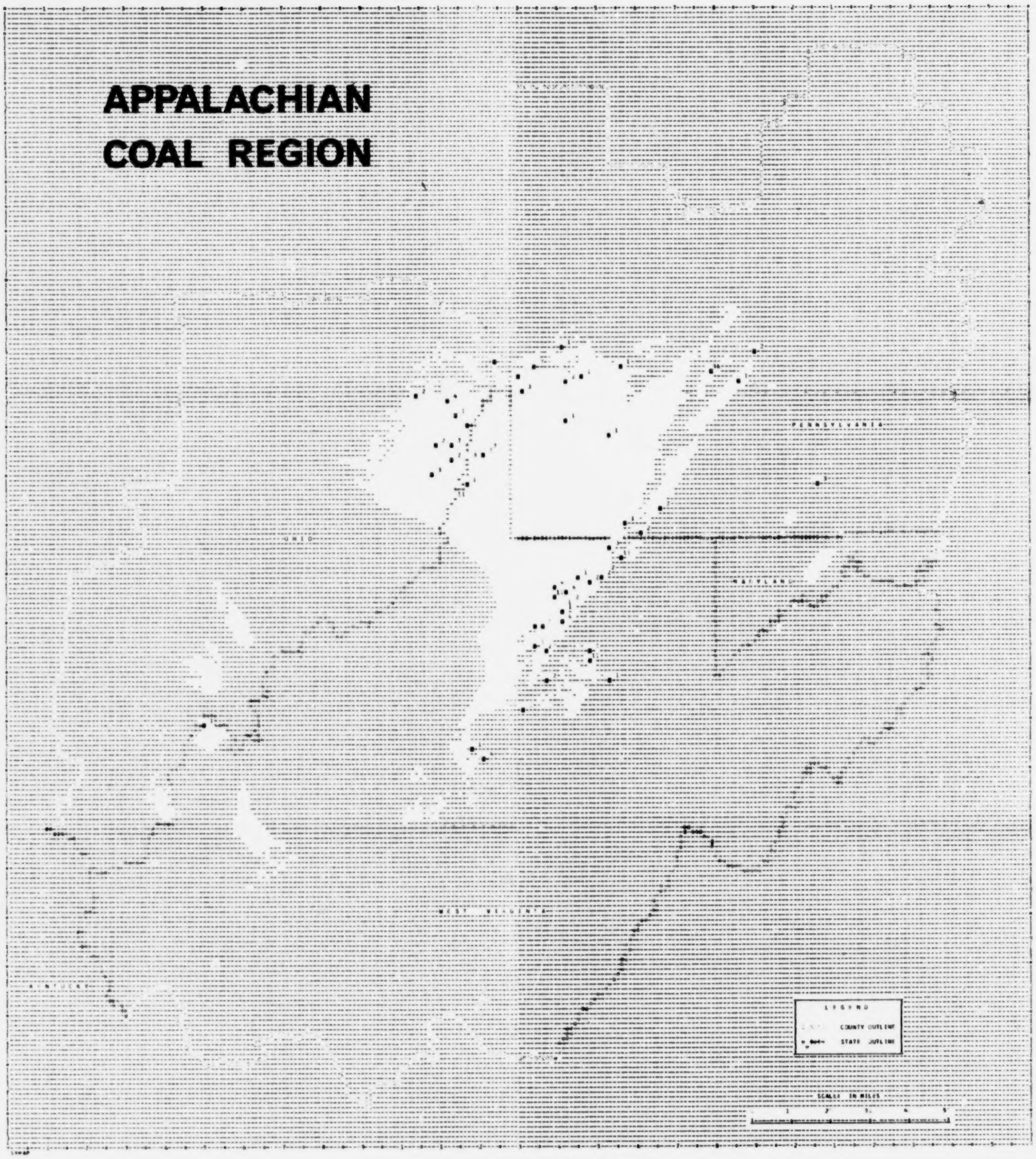
Figures B-2 thru B-4 show the low, mode, and high values for each town; they have the same slope from low sulfur in the northeast to high sulfur in the southwest, as in the county maps but the surfaces are not as smooth, due in part to the greater number of data points and the uneven spread of points. Figures B-5 thru B-7 are identical to B-2 thru B-4 except for the value range intervals selected; the critical isolines of 0.5% and 1% sulfur content are shown. These maps clearly show at a glance that there are no areas with 0.5% or less sulfur coal and very few areas with 1.0% or less sulfur coal.

Figures B-9 thru B-11 show the low, mode, and high values for the raw samples and Figures B-12 thru B-14 the same surfaces for the critical value range intervals. We would assume that fewer areas would be shown as low sulfur (less than 1%) than with the washed samples; however, the opposite is true (compare Figures B-6 and B-13) due to the larger number of data points for raw samples and particularly the much larger number in the low sulfur northeastern part of the study area (compare Figures B-1 and B-8). It is very important to refer to the base maps when comparing surfaces with different data bases.

Another set of maps was run in Phase II using a limiting search radius of five or ten miles around each data point as a study area outline. This serves several purposes:

1) it is not necessary to take the time to code the bed outcrop as an outline, and

2) equal accuracy is maintained for all areas mapped; no symbolism appears for areas without data points such as the southwestern part of Pennsylvania. Figure B-15 shows the base map for this set of maps; the data point locations are exactly



```
        FOUR-STATE COAL REGION
PITTSBURGH BED - WASHED NUMBER OF ANALYSES
    EXPRESSED AS AN ABSOLUTE BY TOWN

DATA VALUE EXTREMES ARE      [illegible]      [illegible]

  MINIMUM      [illegible]
  MAXIMUM      [illegible]

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

            100.0%

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1
          ***********

  SYMBOLS       0

          ***********
  FREQ.        56
```

Figure B-1
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Number of Analyses for Washed Samples
Base Map

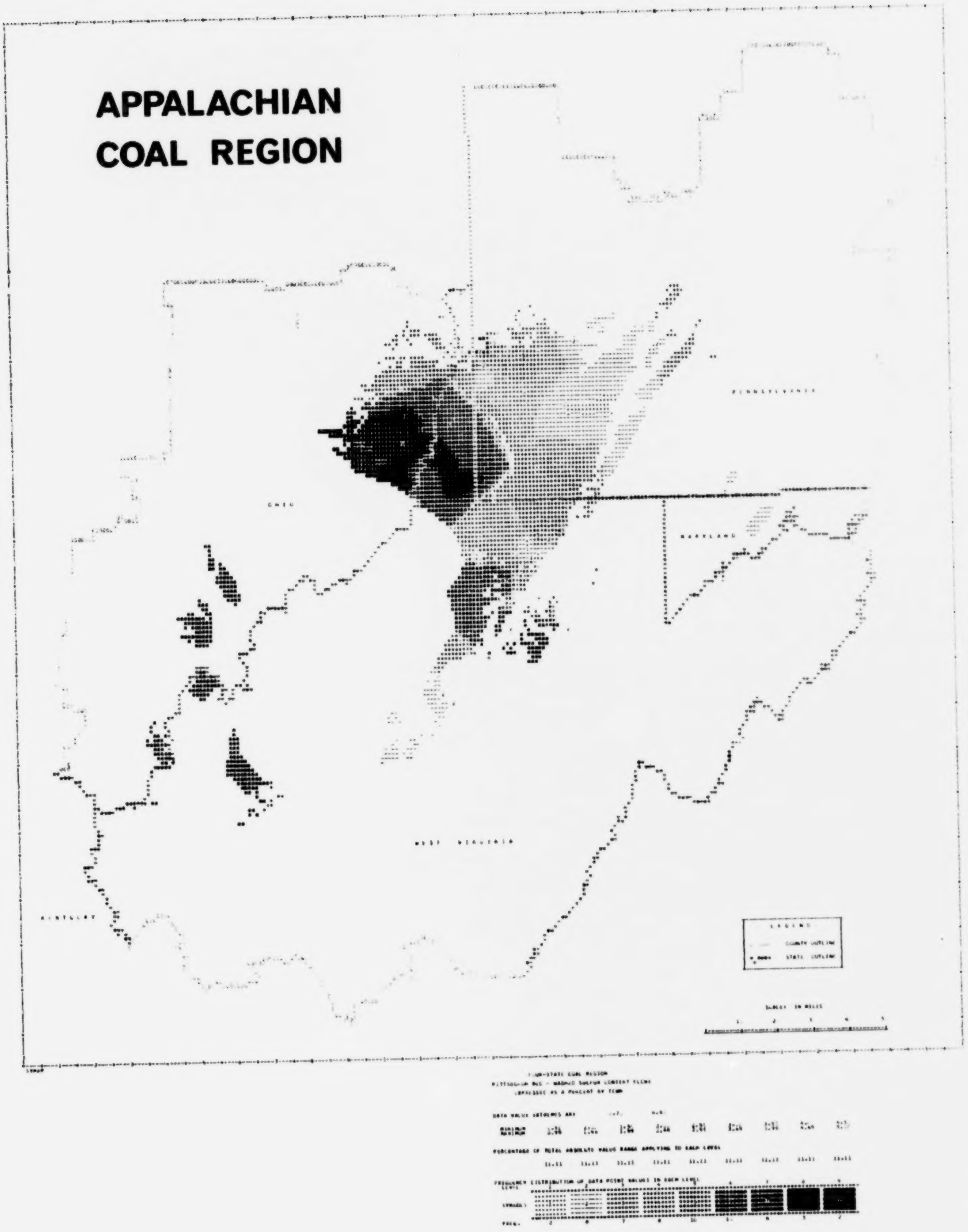


Figure B-2
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Washed Samples
(0.5% isoline interval)

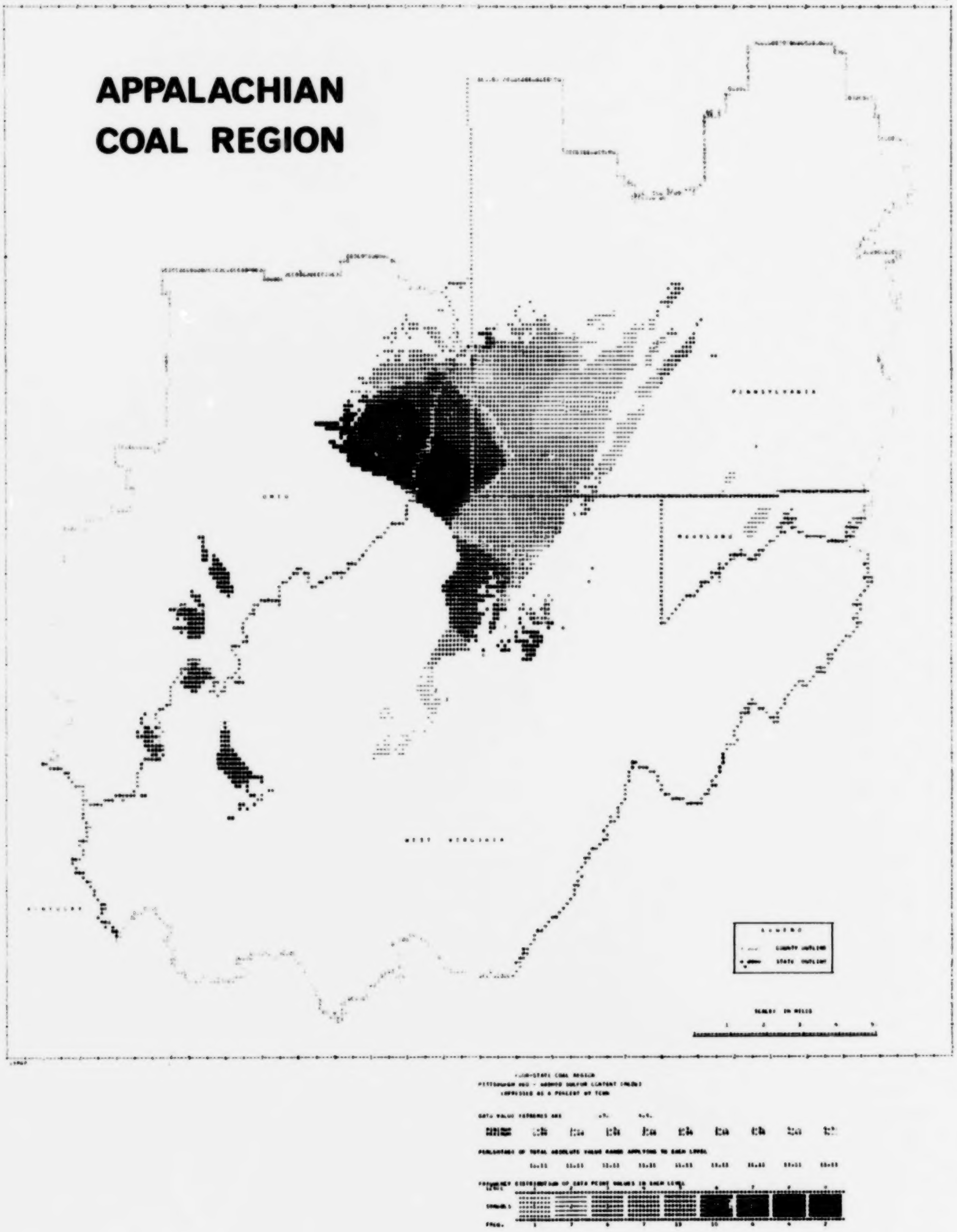


Figure B-3
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Washed Samples
(0.5% isoline interval)

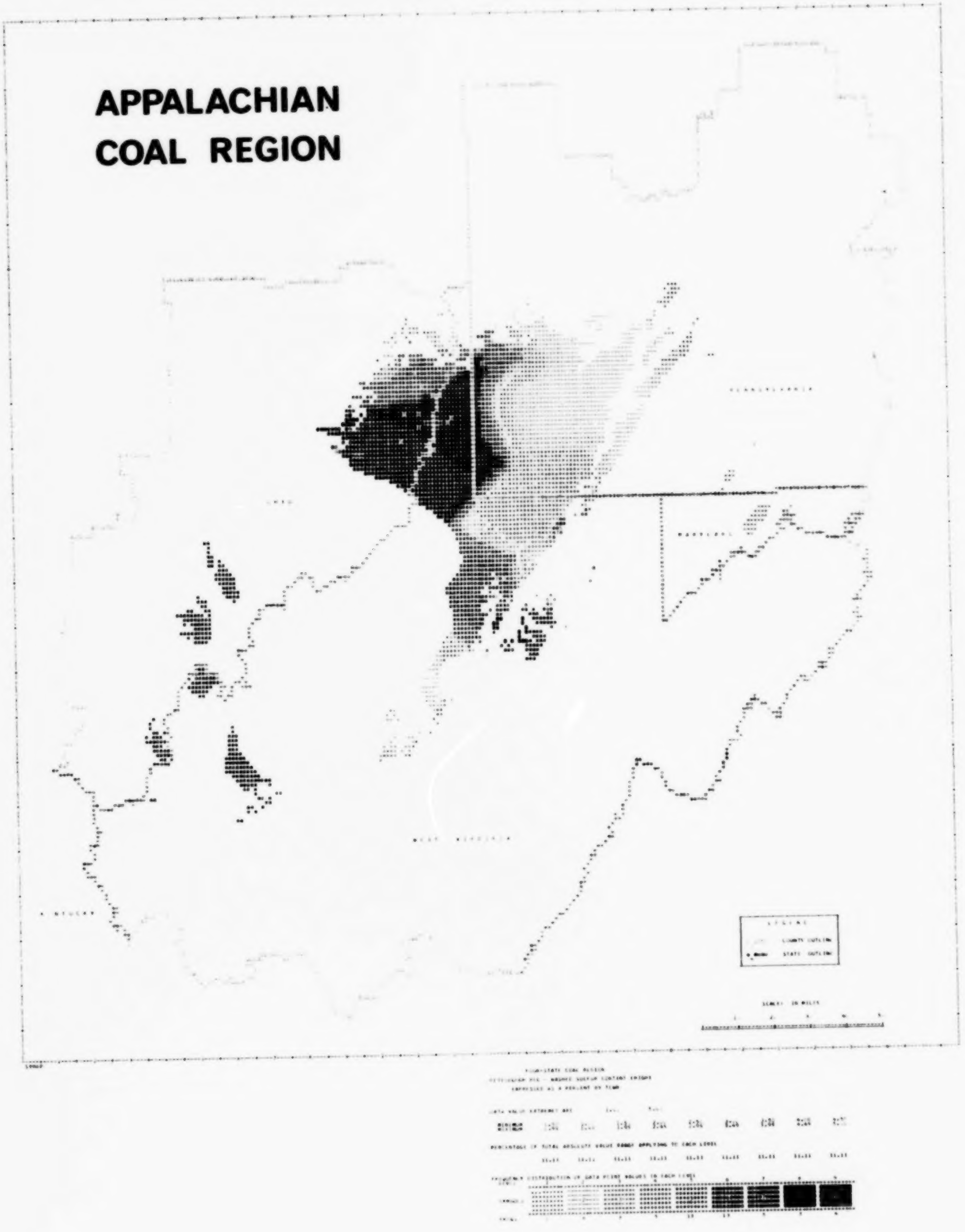


Figure B-4
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Value for Washed Sample
(0.5% isoline interval)

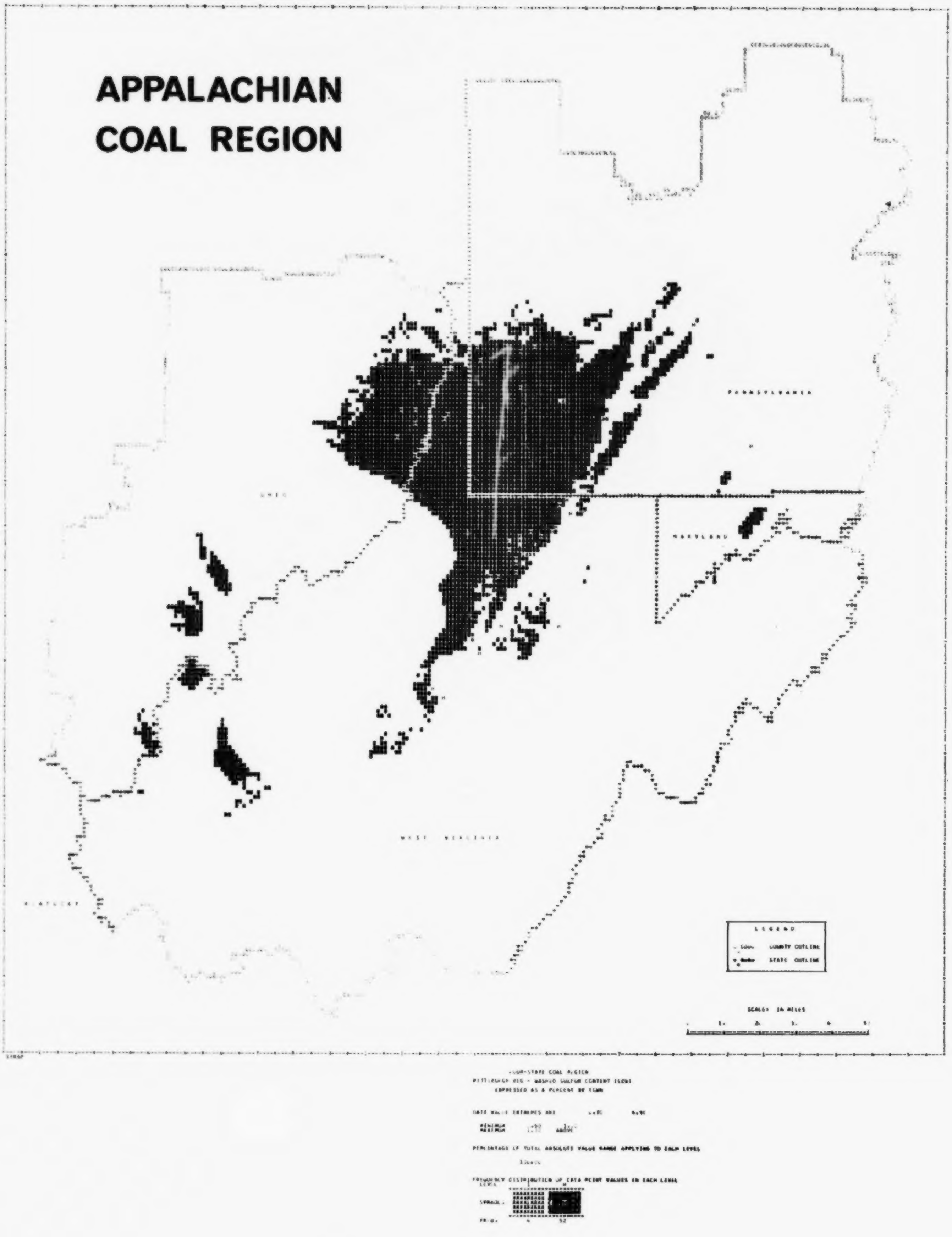


Figure B-5
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Washed Samples
(1% and 1/2% isolines)

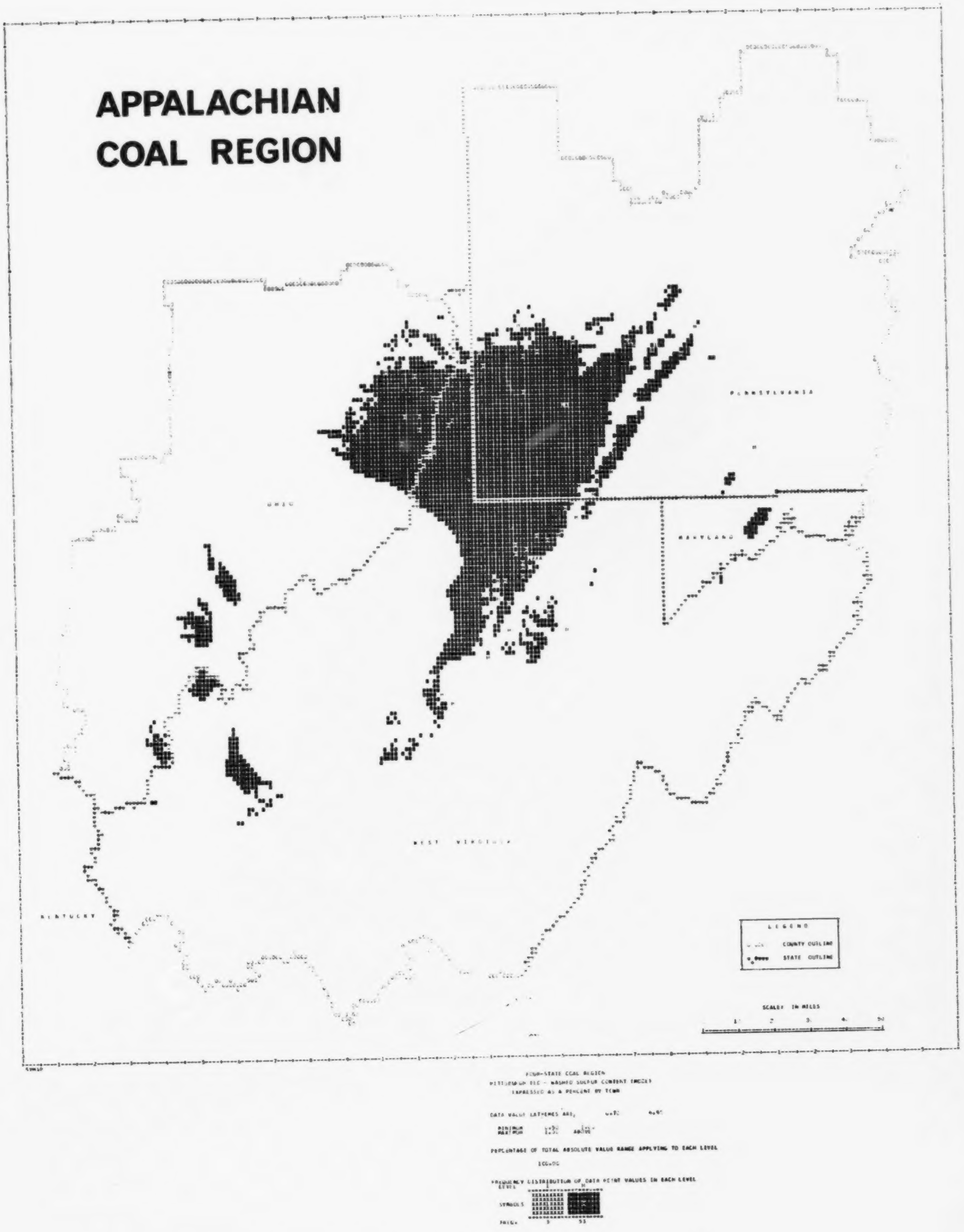


Figure B-6
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Washed Samples
(1% and 1/2% isolines)

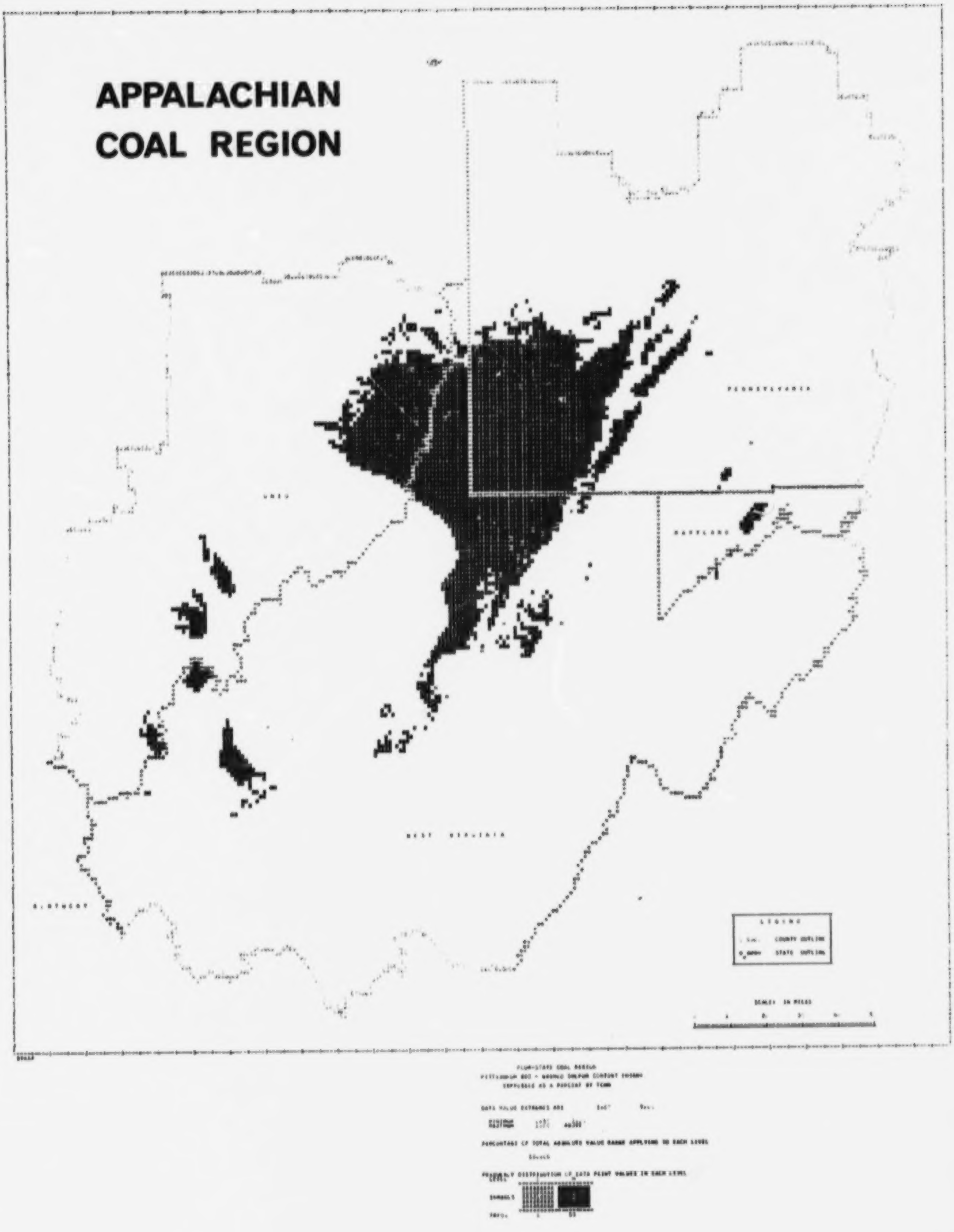


Figure B-7
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Washed Samples
(1% and 1/2% isolines)

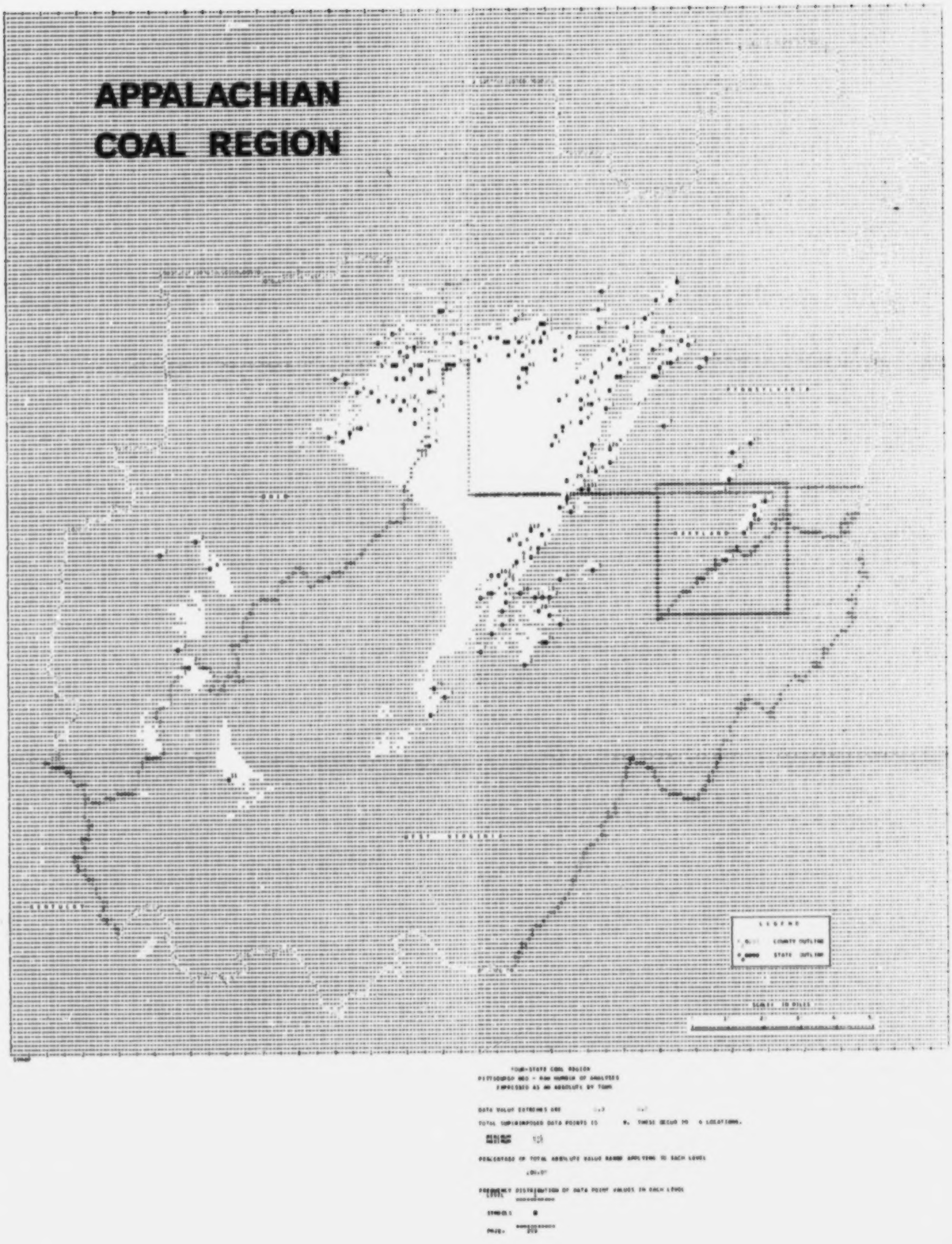


Figure B-8
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Number of Analyses for Raw Samples
Base Map

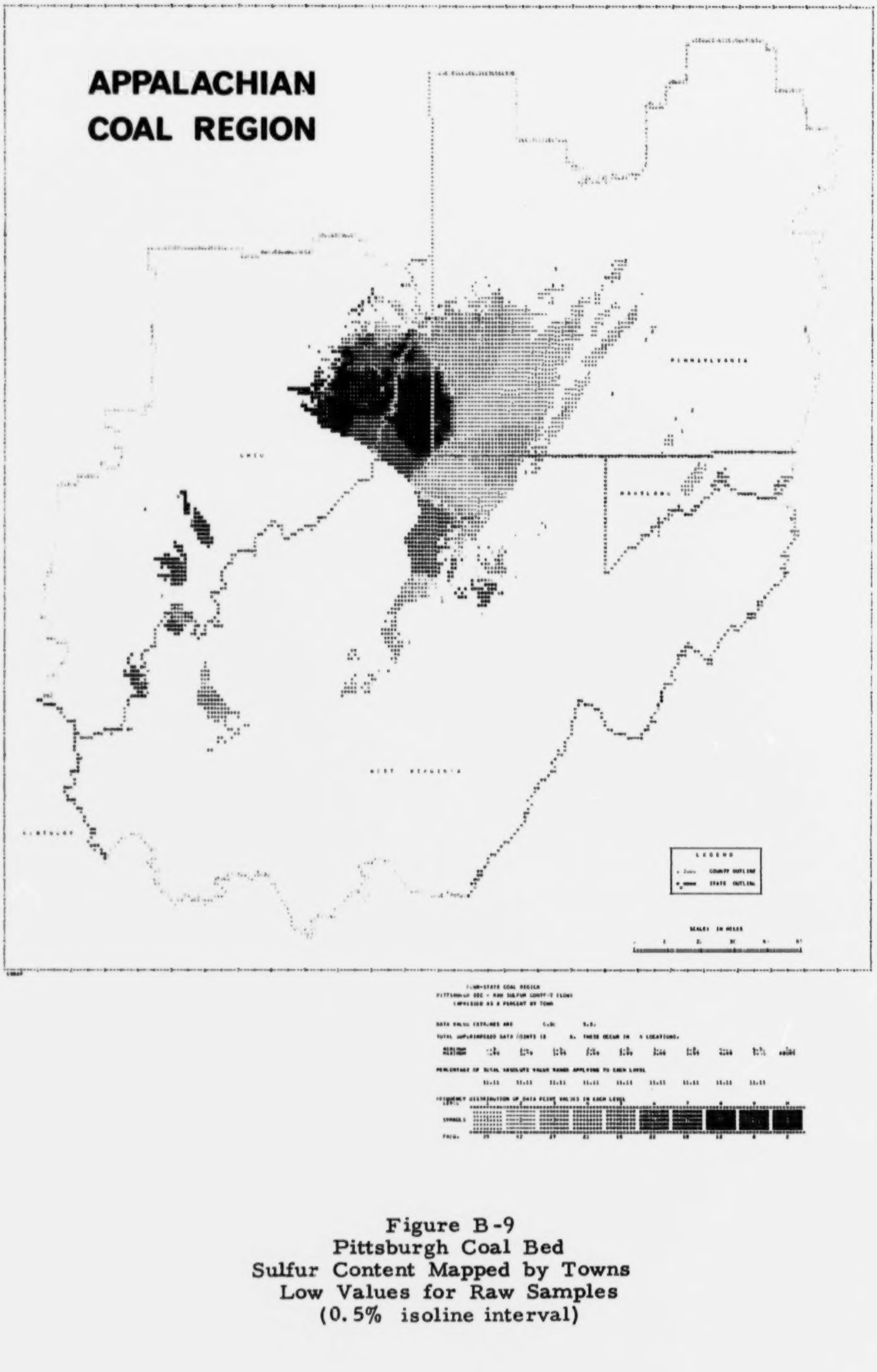


Figure B-9
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
(0.5% isoline interval)

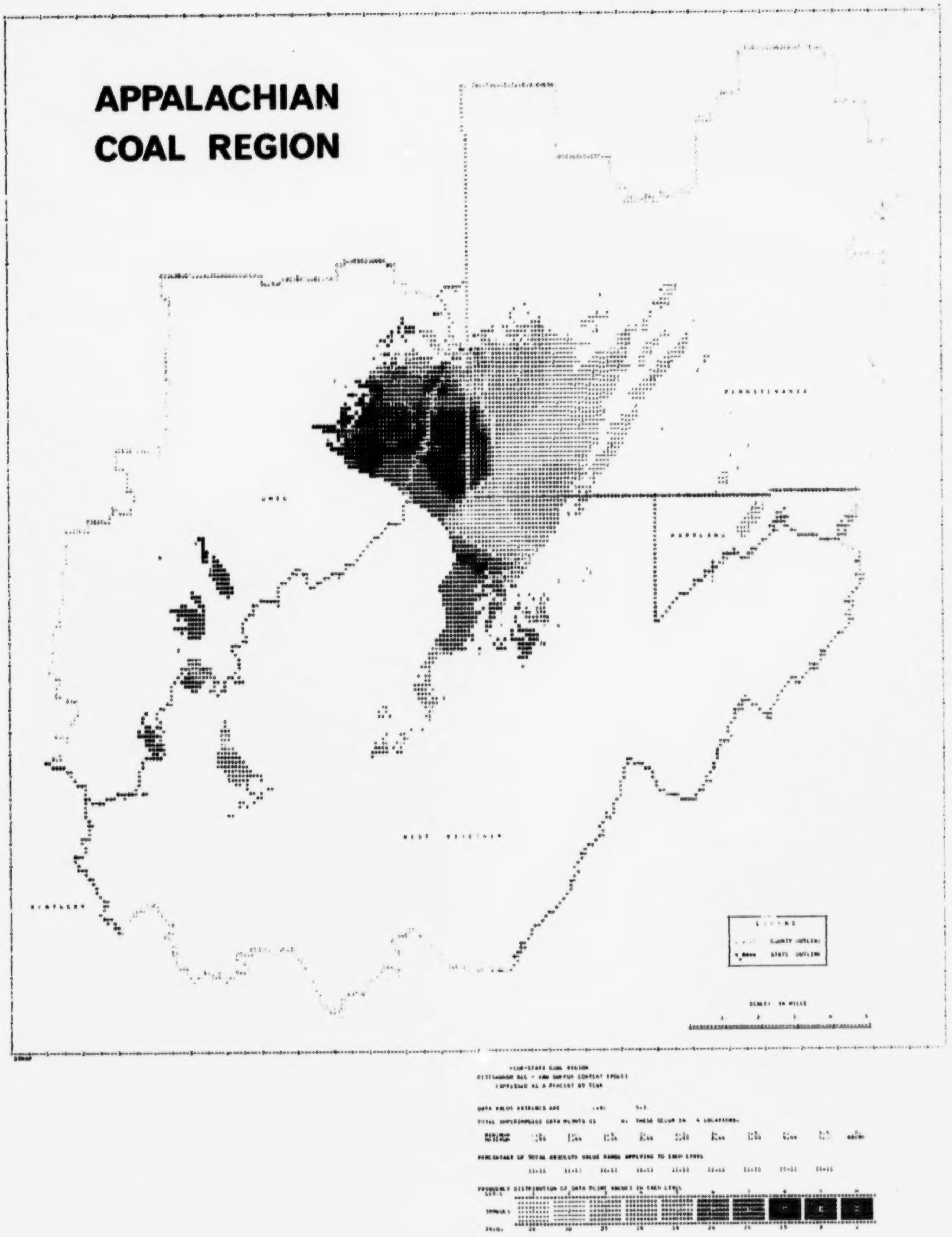


Figure B-10
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
(0.5% isoline interval)

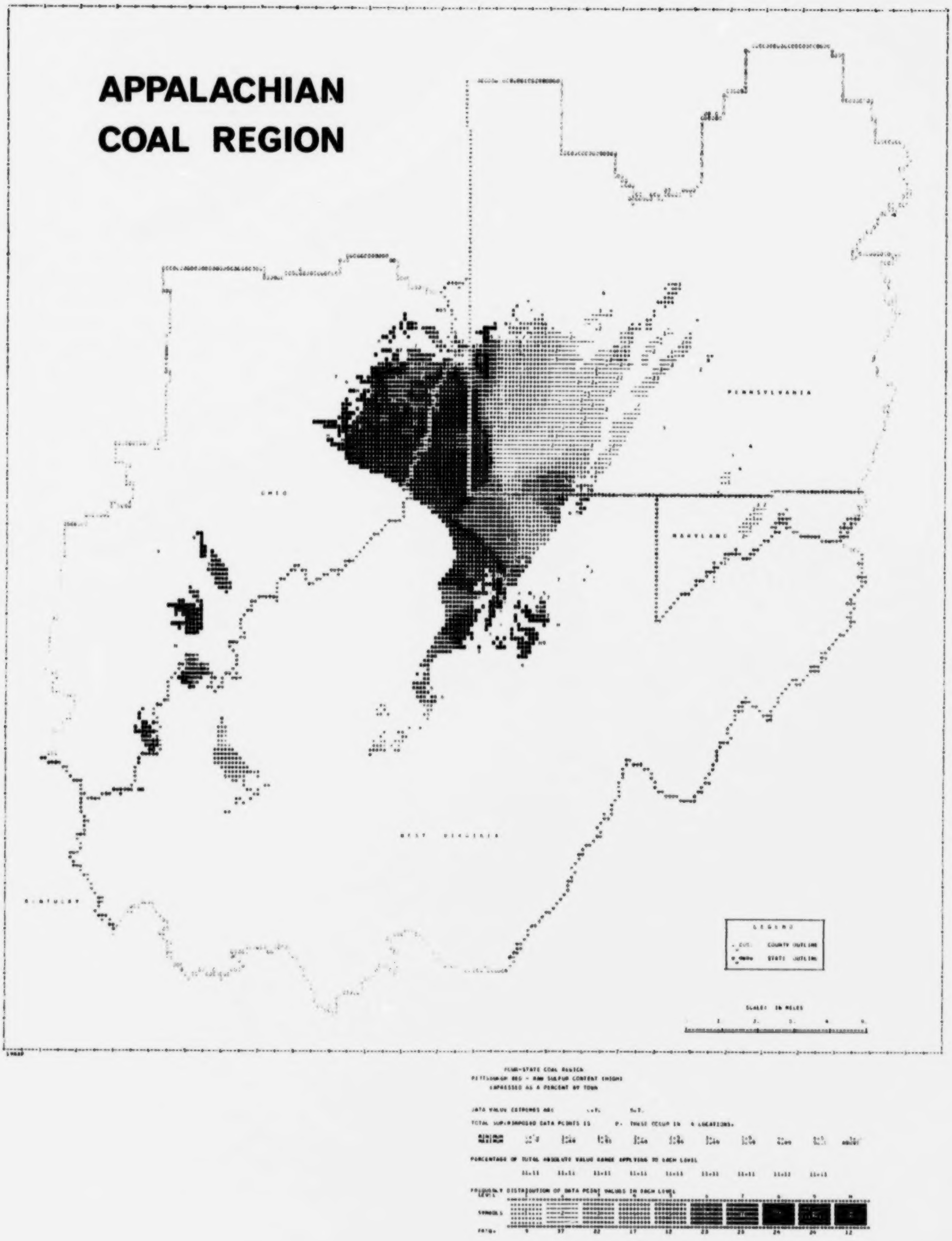

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (HIGH)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE
TOTAL SUPERIMPOSED DATA POINTS IS
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure B-11
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
(0.5% isoline interval)

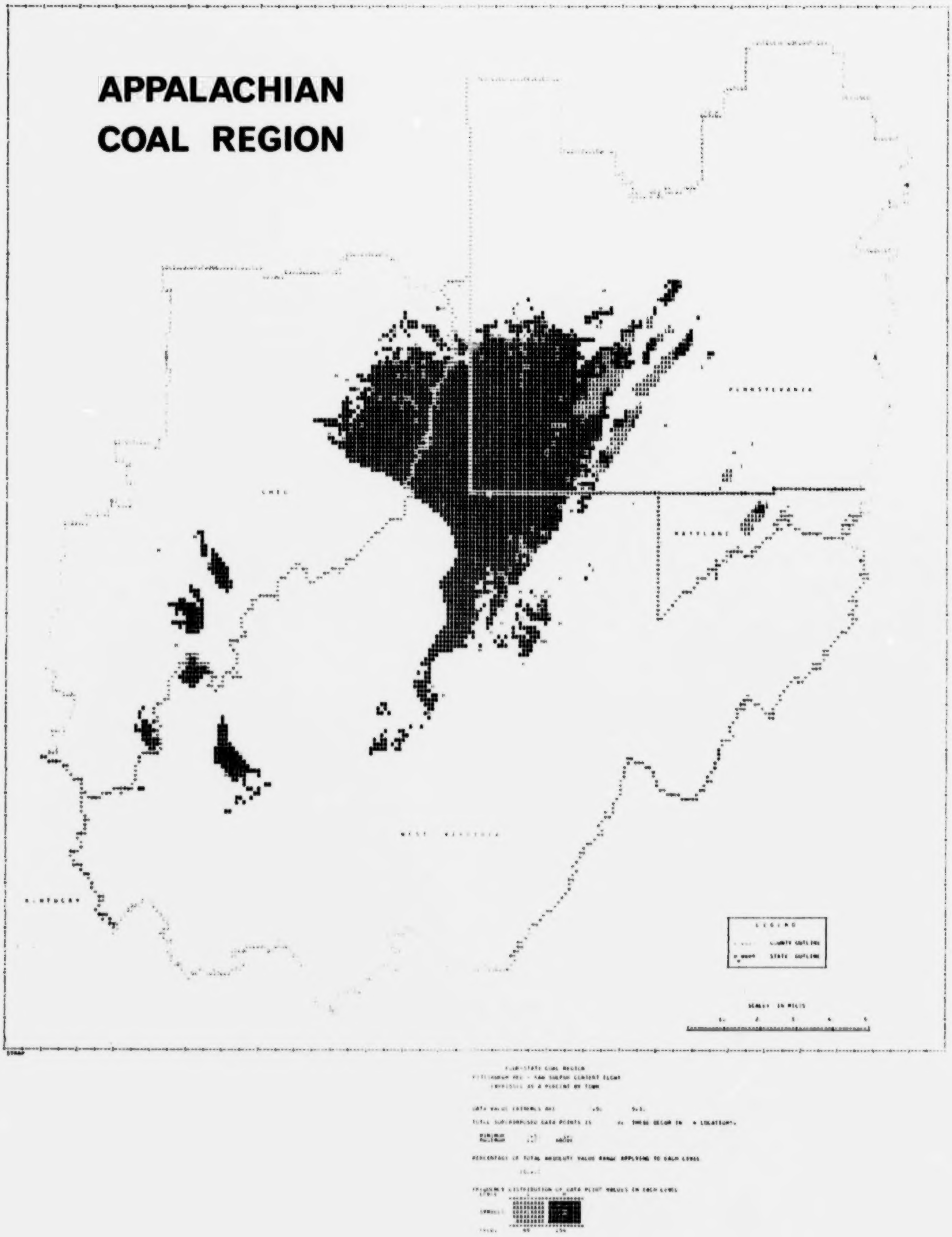


Figure B-12
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
(1% and 1/2% isolines)

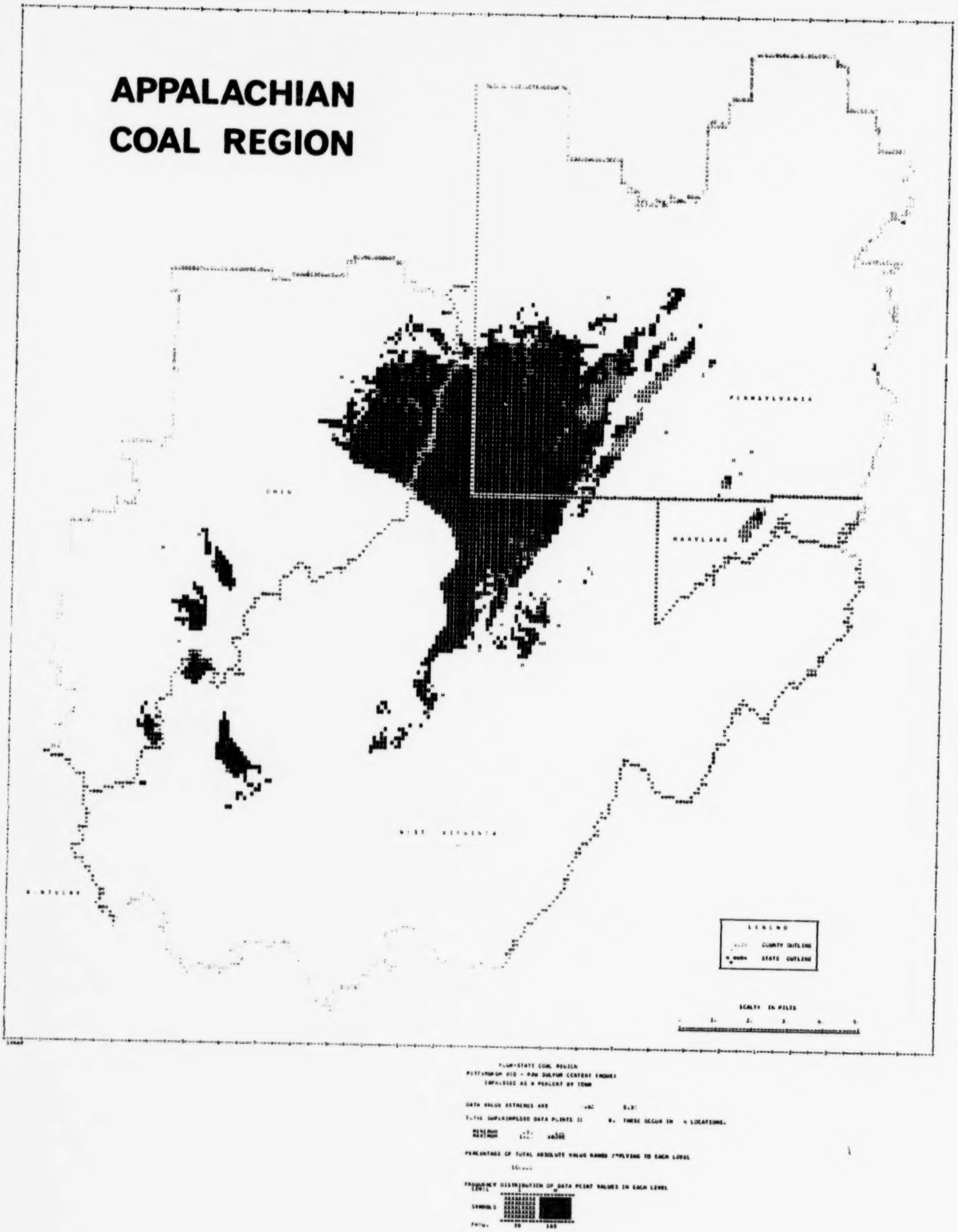
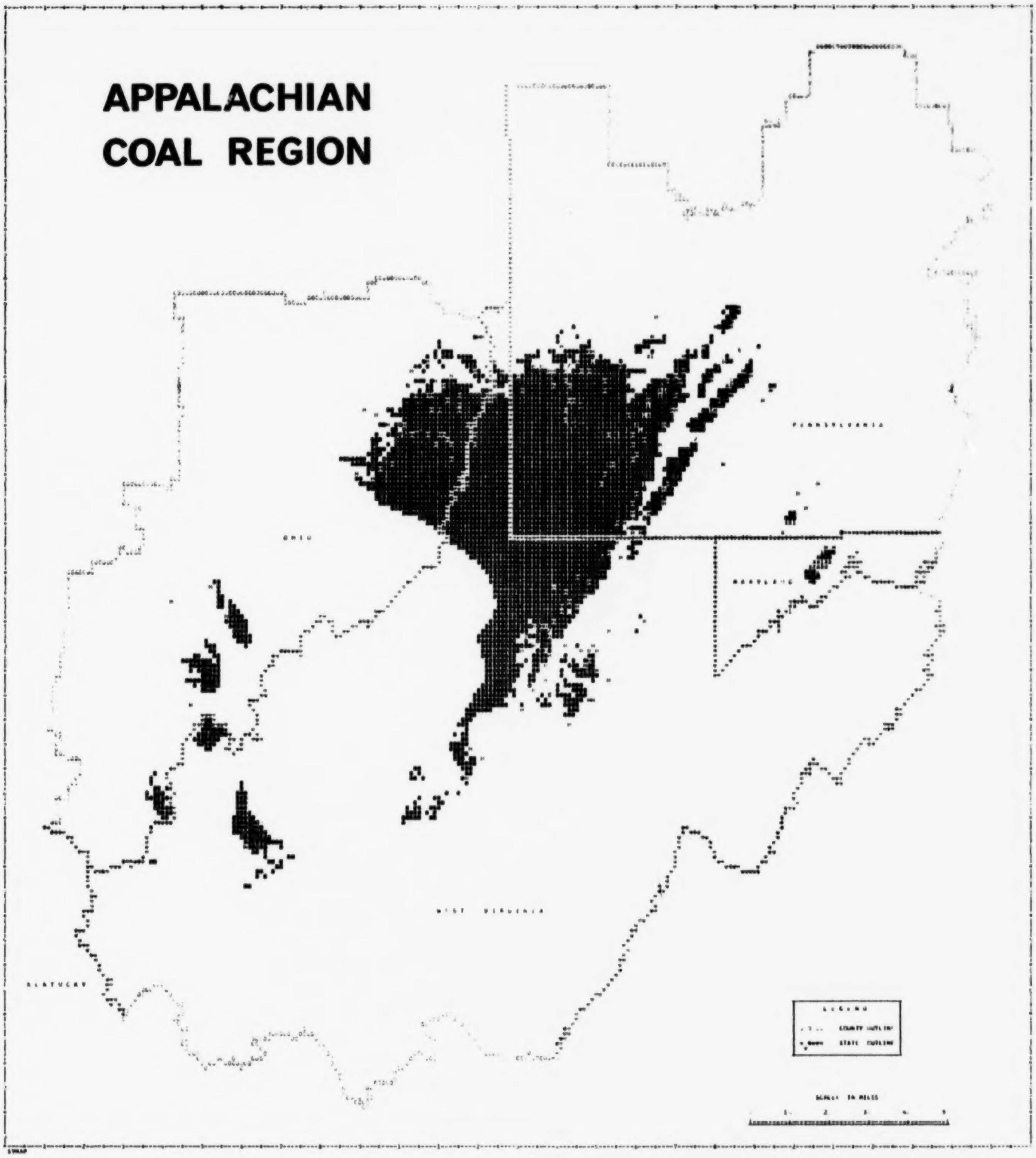
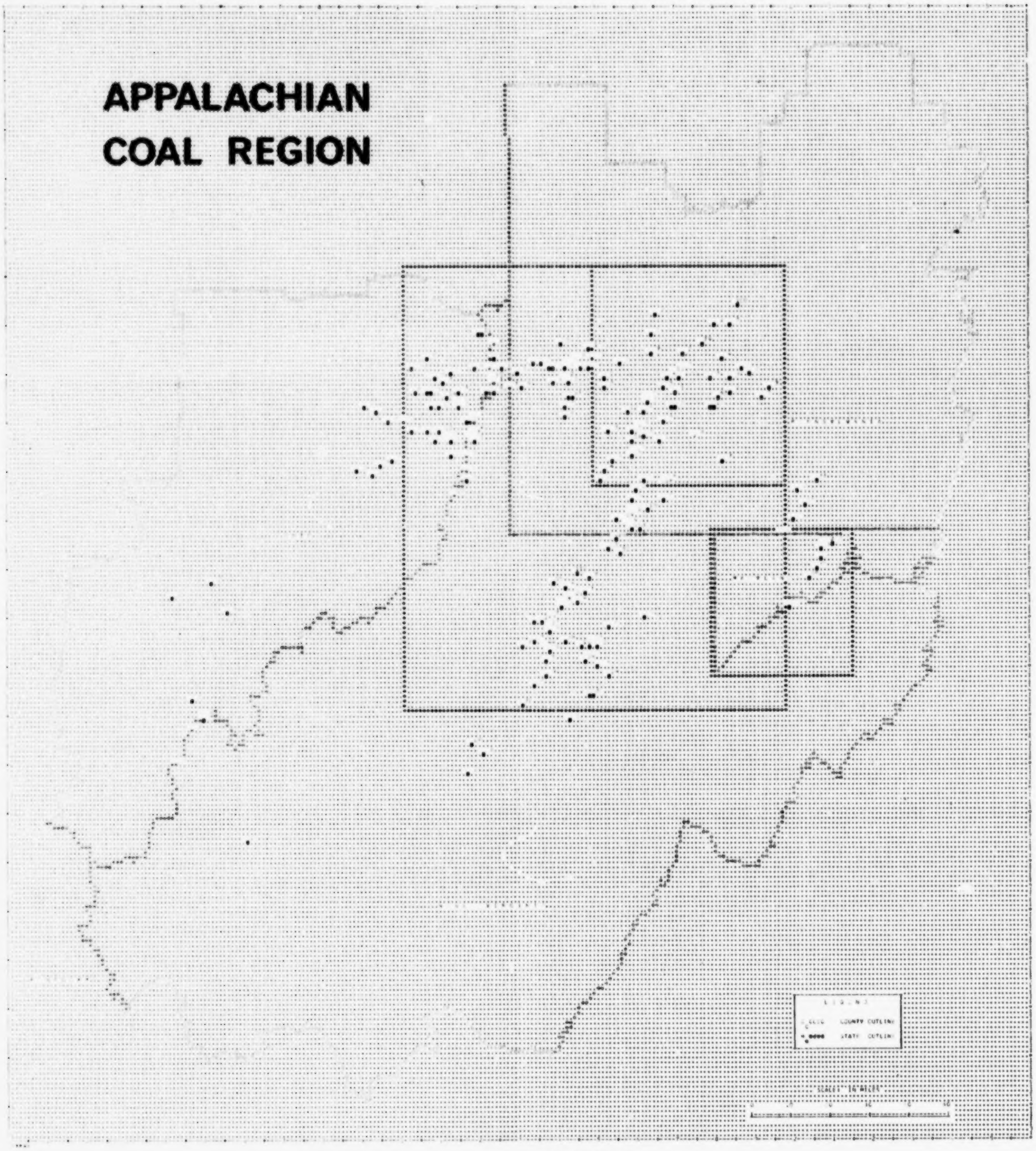

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (MODE)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE
TOTAL SUPERIMPOSED DATA POINTS IS
THESE OCCUR IN
LOCATIONS.
MINIMUM
MAXIMUM
ABOVE
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.
20
105

Figure B-13
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
(1% and 1/2% isolines)



```
        FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (HIGH)
     EXPRESSED AS A PERCENT BY TOWN

DATA VALUE EXTREMES ARE        .72        9.7.

TOTAL SUPERIMPOSED DATA POINTS IS      8.  THESE OCCUR IN   4 LOCATIONS.

 MINIMUM      .50      1.0
 MAXIMUM     1.00     ABOVE

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

            10.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL         1          2

 SYMBOLS

 FREQ.        17        106
```

Figure B-14
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
(1% and 1/2% isolines)



```
          FOUR-STATE COAL REGION
PITTSBURGH BED - RAW NUMBER OF ANALYSES
      EXPRESSED AS AN ABSOLUTE BY TOWN

DATA VALUE EXTREMES ARE        0.0         0.0

TOTAL SUPERIMPOSED DATA POINTS IS       0.  THESE OCCUR IN   0 LOCATIONS.

  MINIMUM      0.0
  MAXIMUM      0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

          100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL        1

  SYMBOLS

  FREQ.      273
```

Figure B-15
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Number of Analyses for Raw Samples
Base Map - 5 Mile Search Radius

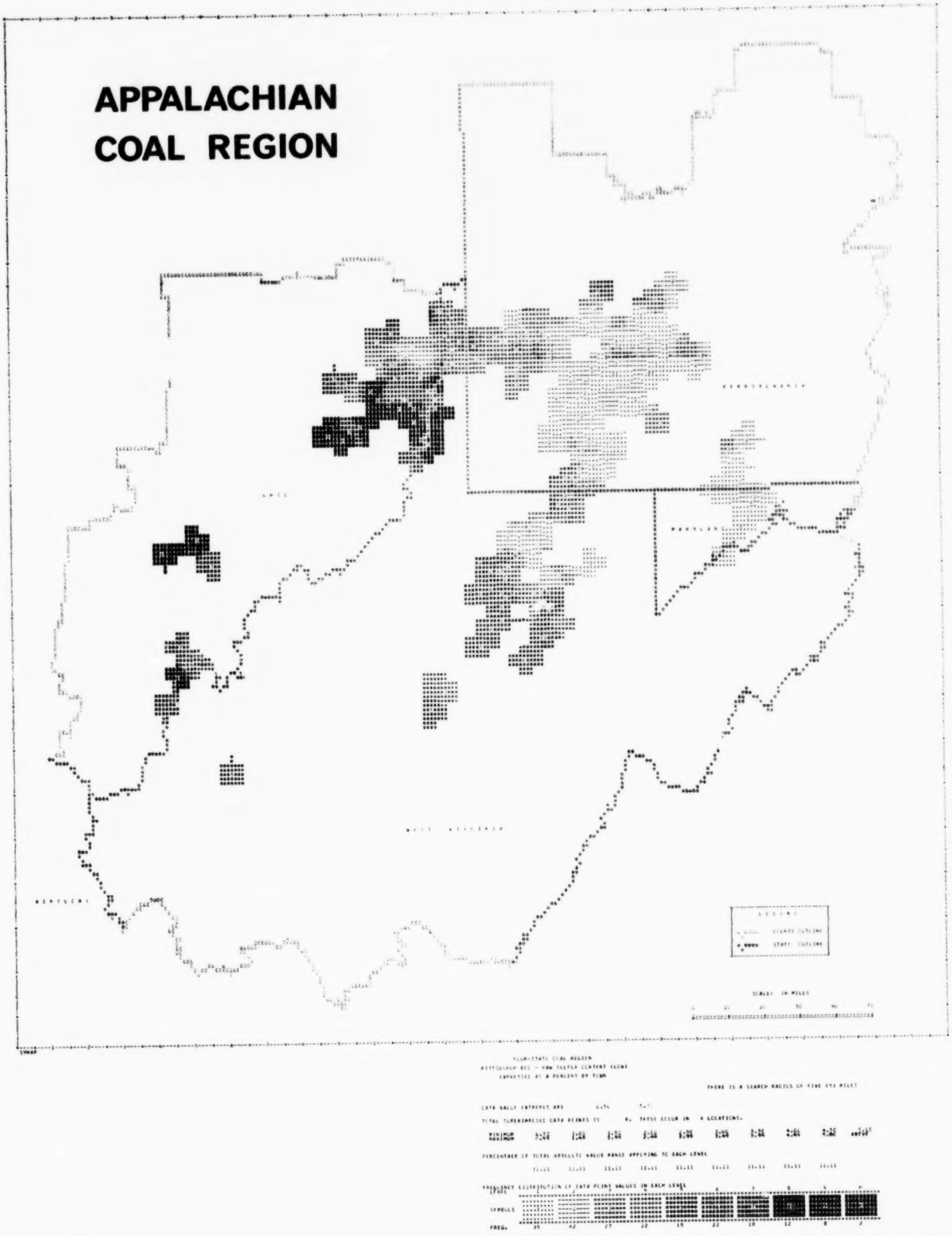


Figure B-16
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
5 Mile Search Radius

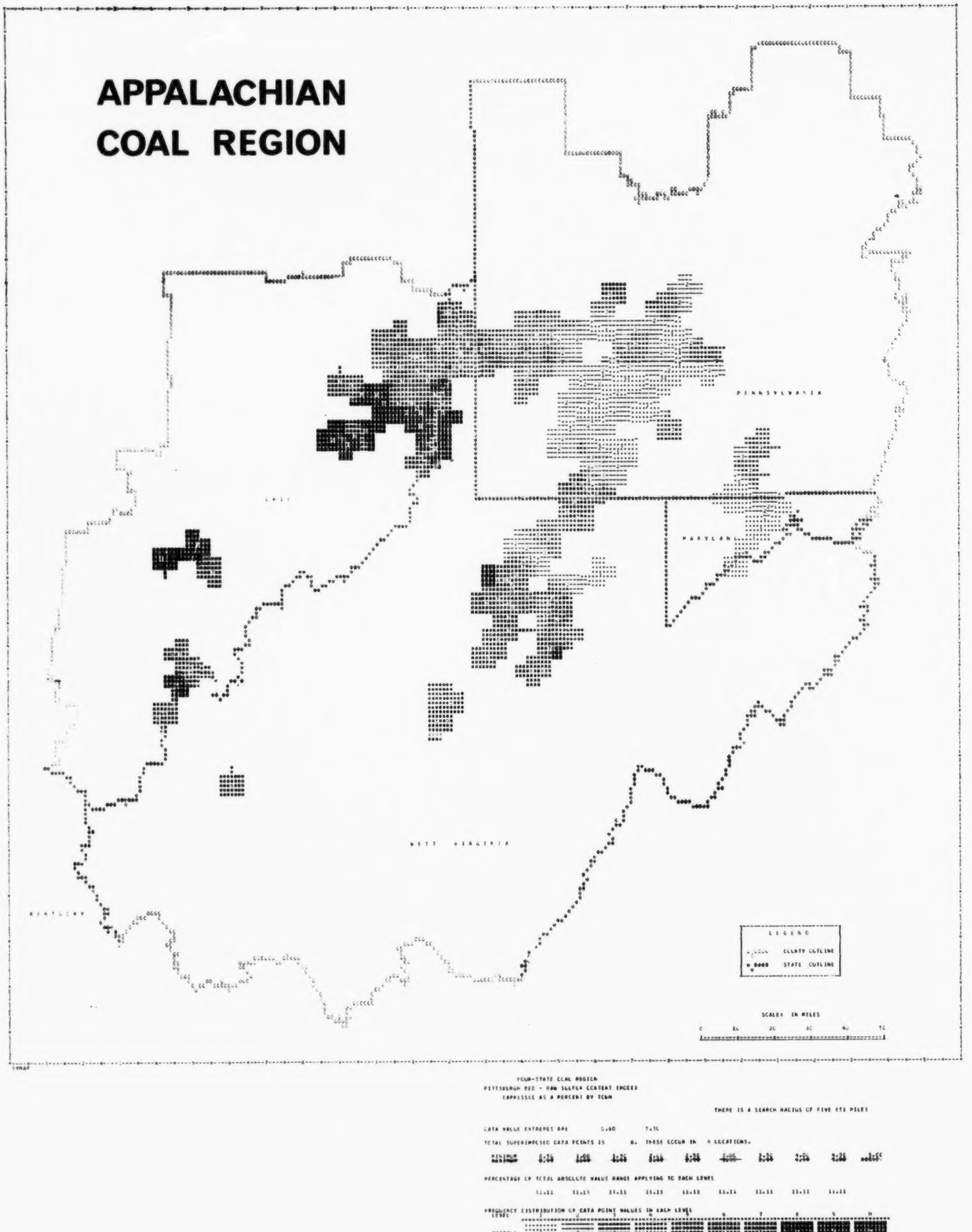

APPALACHIAN
COAL REGION
PENNSYLVANIA
MARYLAND
OHIO
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE: IN MILES
0
10
20
30
40
50
FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT INDEX
EXPRESSED AS A PERCENT BY TON
THERE IS A SEARCH RADIUS OF FIVE (5) MILES
DATA VALUE EXTREMES ARE 0.60 5.36
TOTAL SUPERIMPOSED DATA POINTS IS 0. THESE OCCUR IN 4 LOCATIONS.
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
1
2
3
4
5
6
7
8
9
10
SYMBOLS
FREQ.
26
30
23
24
19
24
26
19
8
2

Figure B-17
Pittsburgh Coal Bed
Sulfur Conten Mapped by Towns
Mode Values for Raw Samples
5 Mile Search Radius

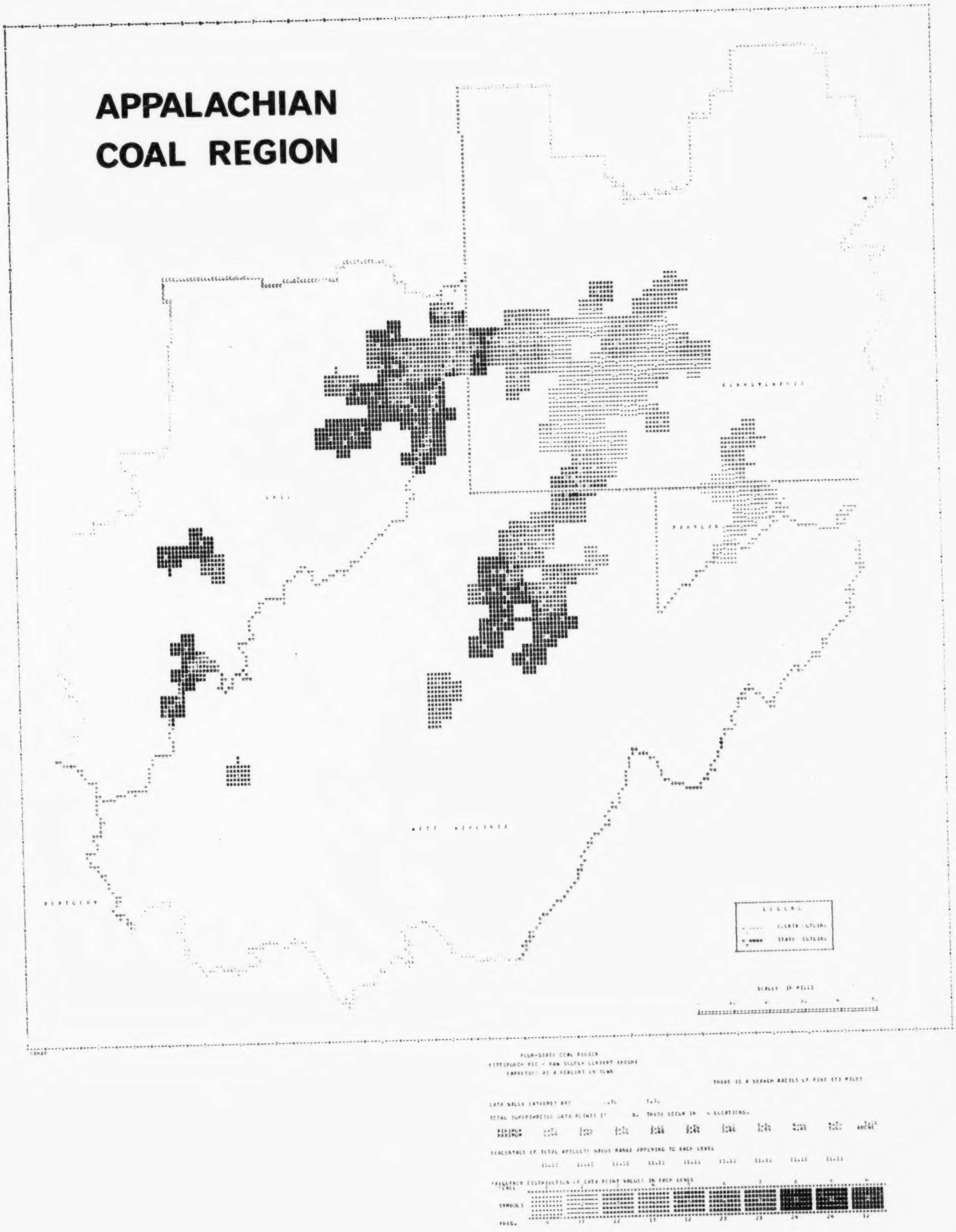


Figure B-18
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
5 Mile Search Radius

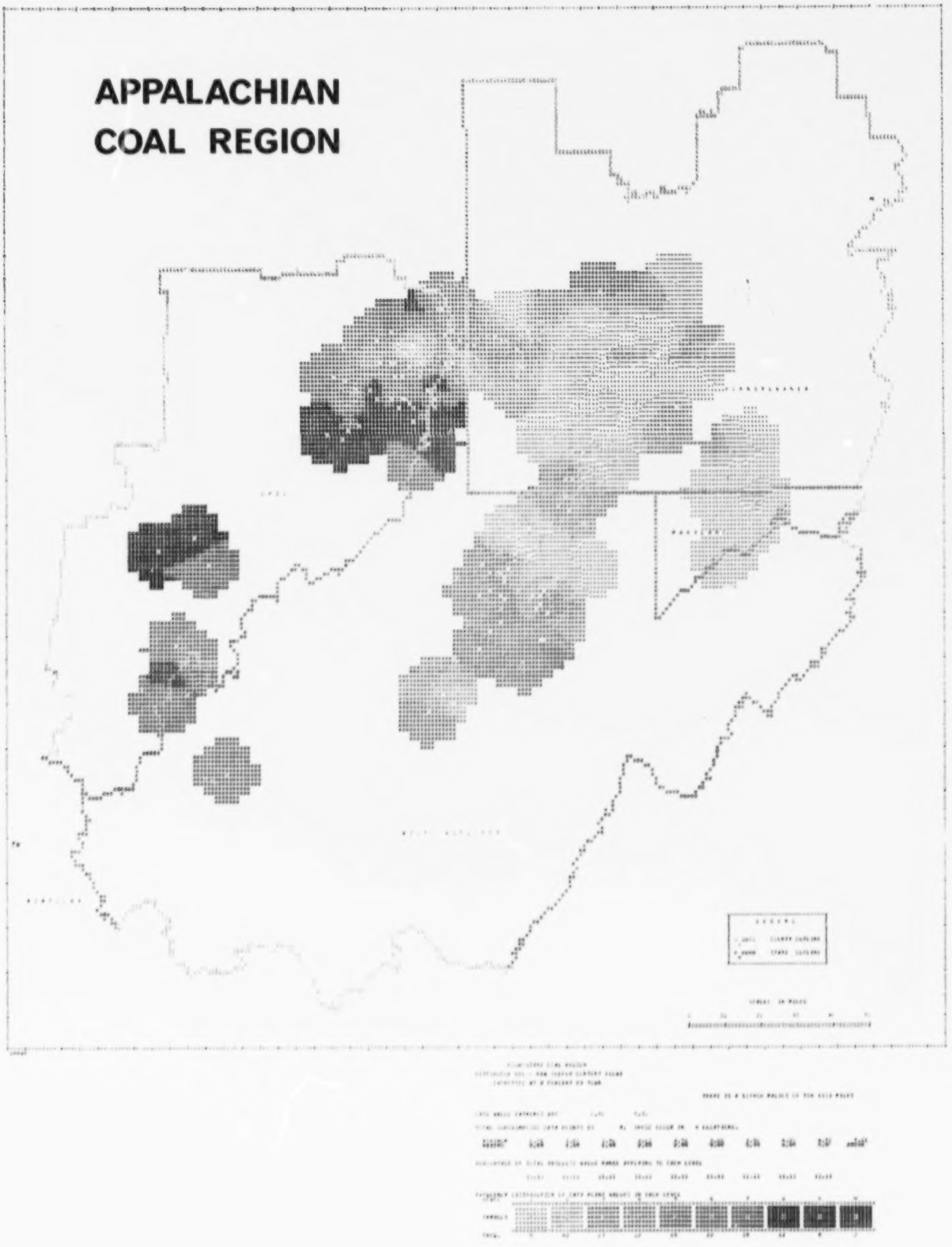


Figure B-19
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
10 Mile Search Radius

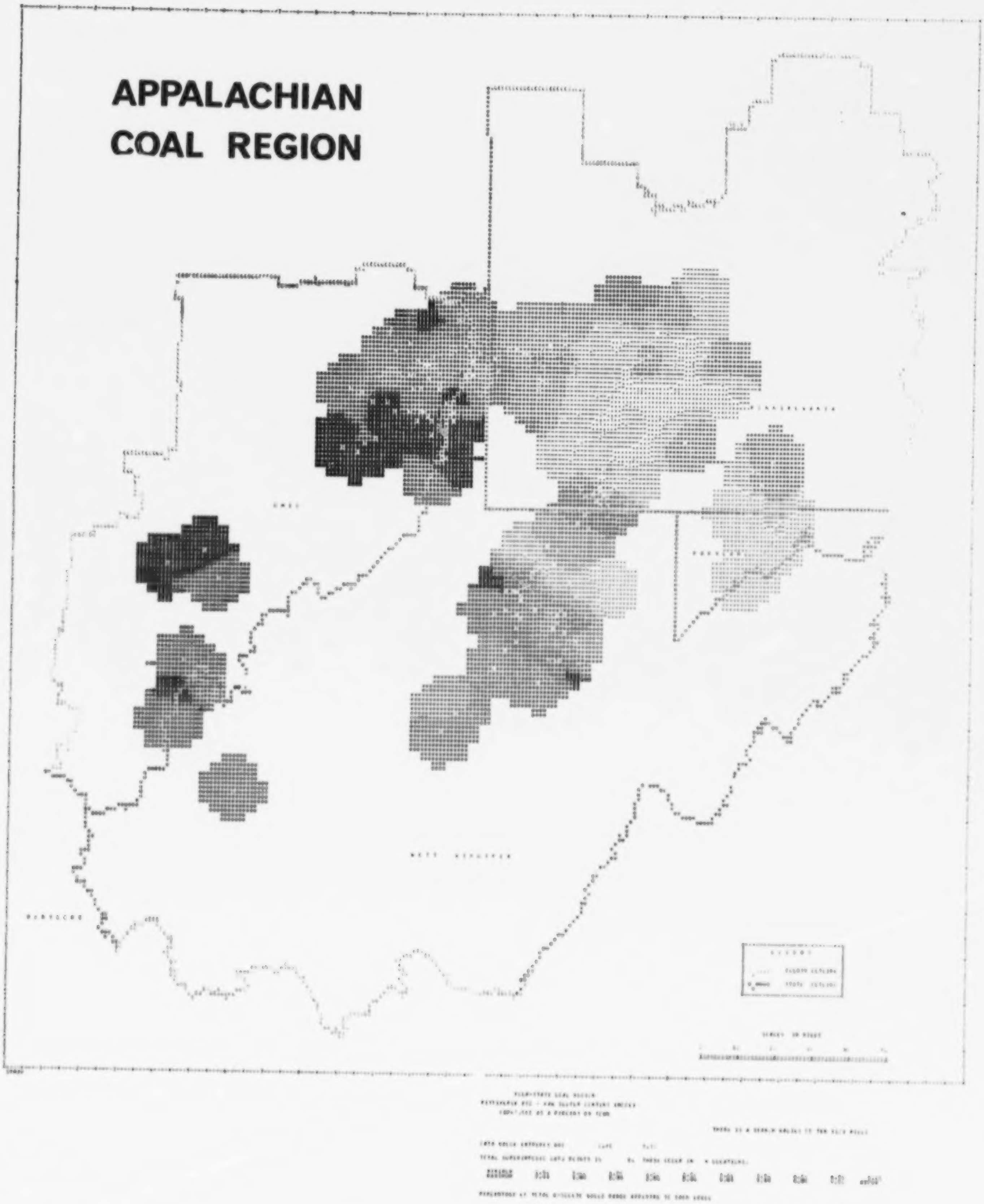


Figure B-20
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
10 Mile Search Radius

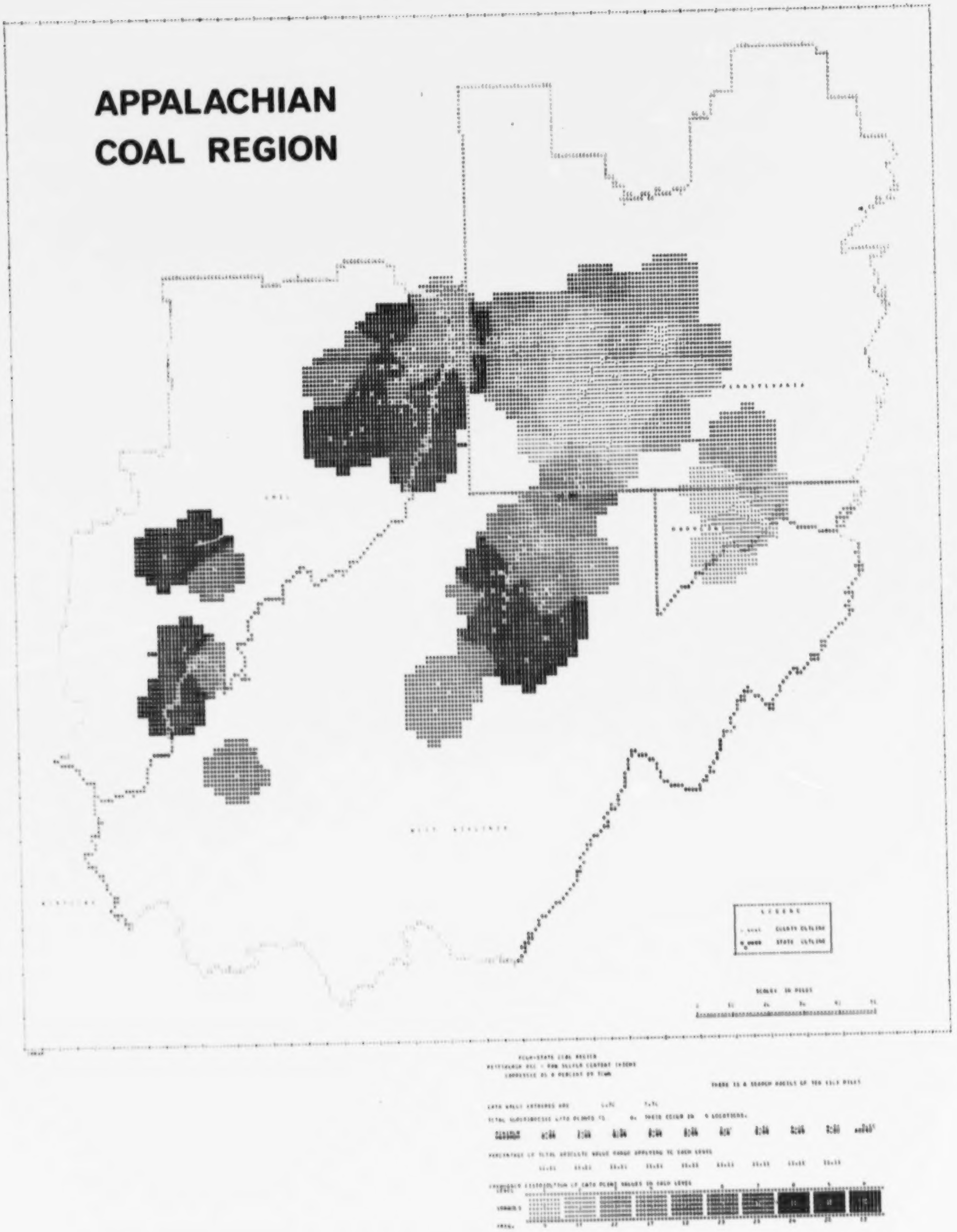


Figure B-21
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
10 Mile Search Radius

the same as those shown in Figure B-8. The portions of the study area enlarged in map series D are shown by rectangular borders. Figures B-16 thru B-18 show the low, mode, and high values for the raw samples with a five mile search radius. Figures B-19 thru B-21 depict the identical information with a ten mile search radius. In both cases the same values are mapped as were shown in Figures B-9 thru B-11; in fact, the only differences are in the effective study area outlines.

2.4. MAP SERIES C

For the Middle Kittanning Coal Bed sufficient information was not available to use the bed outcrop as a study area outline. Accordingly, the data for the raw samples were mapped using a five and ten mile search radius as was employed in one set of map series B. Figure C-1 shows the base map for the Middle Kittanning Bed; the data points are very poorly spread out over the study area and are clustered. Figures C-2 thru C-4 show the low, mode, and high values for the raw samples with a five mile search radius; Figures C-5 thru C-7 depict the same information with a ten mile search radius.

These sets of maps do not give us very much information about the extent of the coal seam, or the extent at various sulfur levels. However, they give us as much and as accurate information in the vicinity of the towns (or mines) as if we had known the outcrop area and mapped it. We can choose a search radius based on the reliability we attach to the data and the number and spacing of data point locations. Five miles may be conservative in that the information conveyed graphically is scanty; on the other hand ten miles may be misleading as to the extent of the coal seam in some areas. Finally, it is important to keep in mind that we are dealing with samples aggregated by towns and that the data point locations only represent the nearest town and not the actual mine or sample location.

In examining Figures C-3 and C-6 (the mode values for five and ten mile search radius, respectively) we find that 9 out of 90 or 10% of the towns have mode values of less than 1% sulfur content. This is in contrast to the 26 out of 203 or 13% of the towns with mode values for raw samples less than 1% sulfur content for the Pittsburgh Bed (see Figure B-10). However, the low sulfur data points are more spread out (less clustered) in the Middle Kittanning Bed and therefore give the illusion of greater areas of low sulfur coal.

It is of particular interest to compare the surfaces for the low (Figure C-5), mode (Figure C-6), and high (Figure C-7) values. The surface of mode values is what we would be most apt to find; the surface of low values is hypothetical and shows the lowest sample found for each town, and, likewise, the surface of high values shows the highest values found. Out of the 90 data points 13 are under 1% sulfur content for the low values, 9 for the mode values and only 3 for the high values. In all three cases low sulfur data points are spread throughout the eastern half of the coal region and three points occur in the western half for the low values. The mode values delineate the areas of interest for possible small scale analysis and mapping. The high values tell us that 3 of the 9 areas shown on the surface will have 'all' low sulfur coal, as determined by the samples taken. (Unfortunately, when we refer to the base map--Figure C-1--we find that these three points have only 1, 1, and 7 samples each and, therefore, do not represent a very good statistical sample; however, the use of the map of high values with the one of mode values is still informative). On the other hand the map of low values tells us

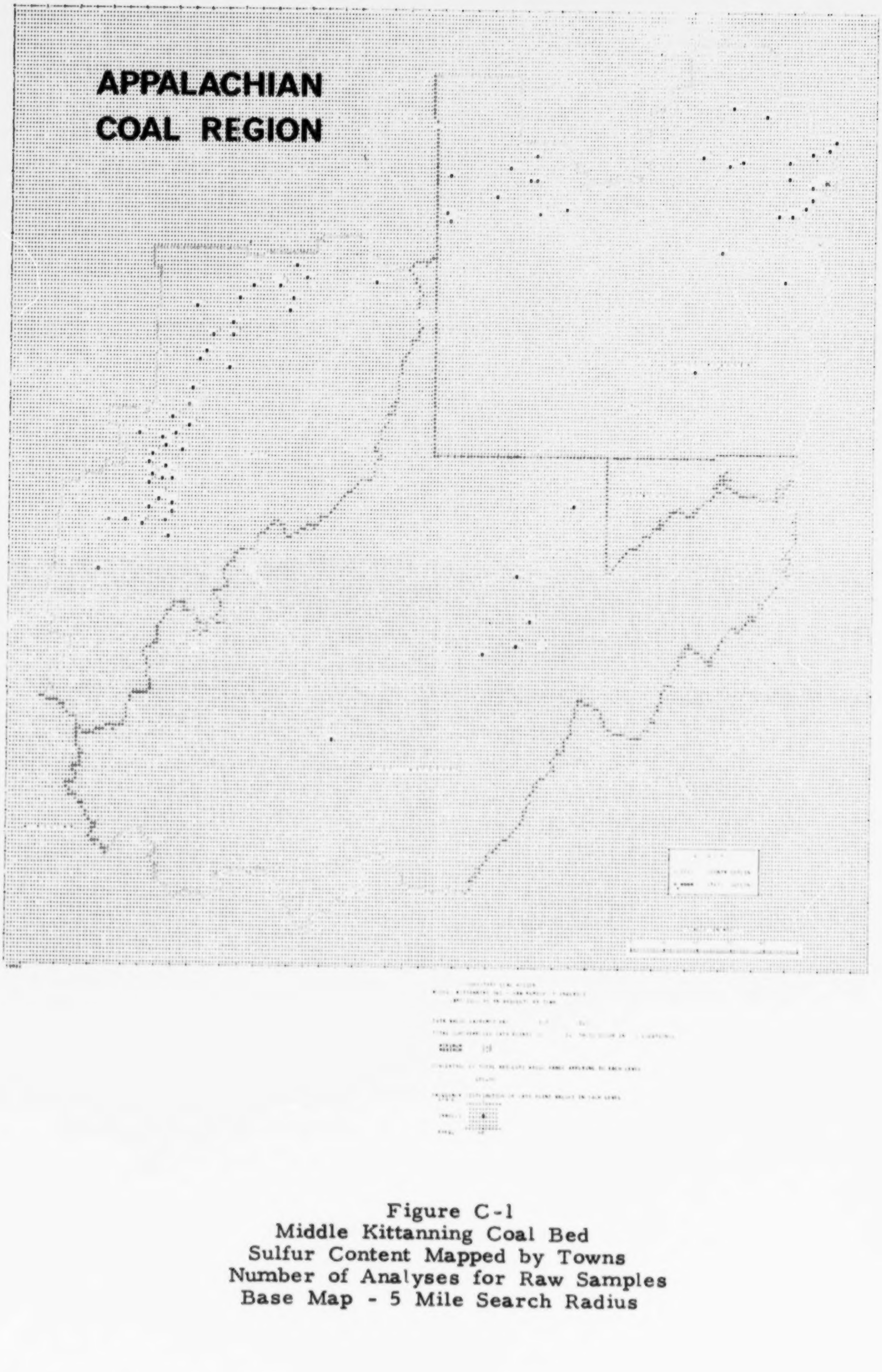


Figure C-1
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Number of Analyses for Raw Samples
Base Map - 5 Mile Search Radius

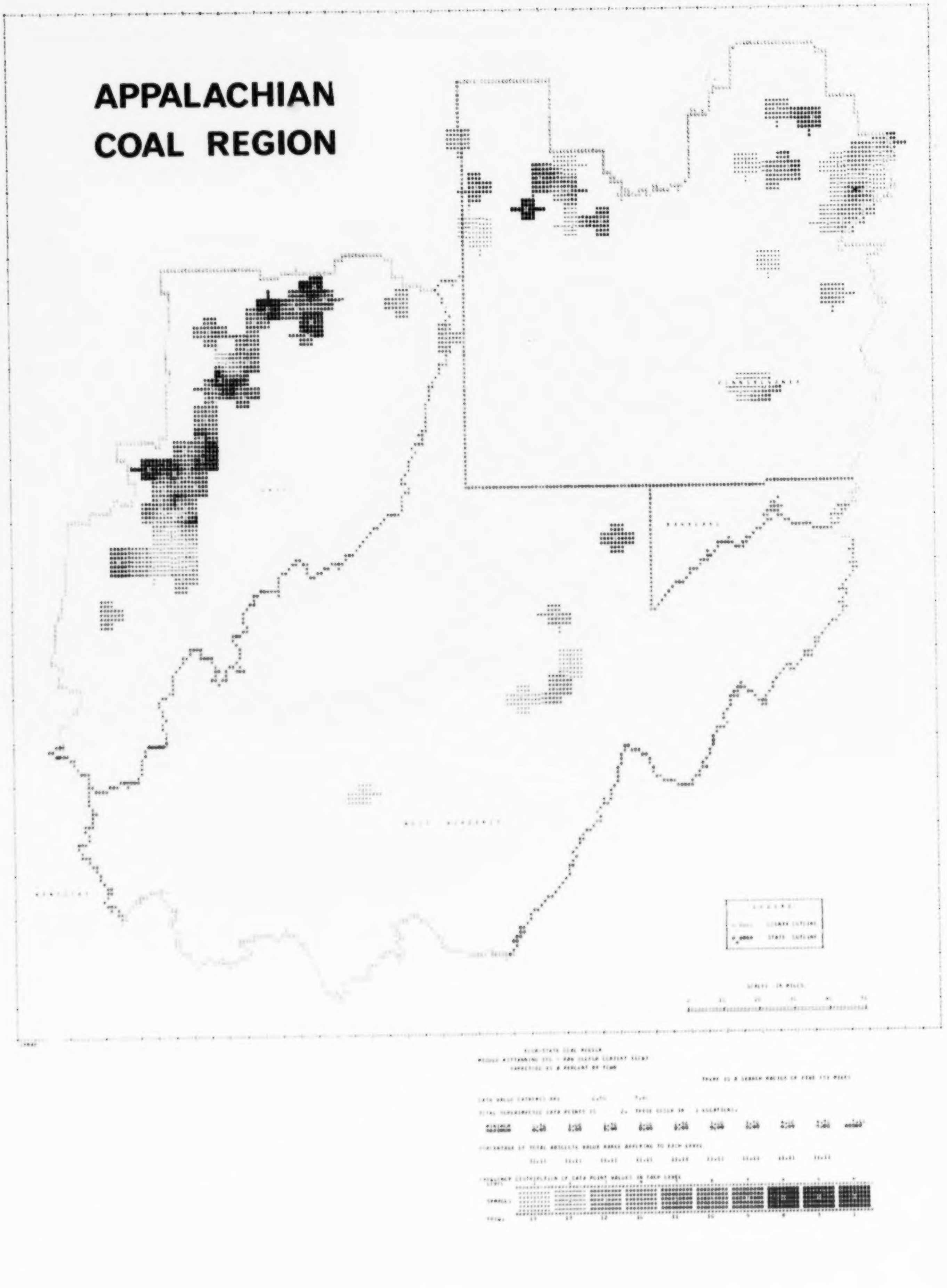


Figure C-2
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
5 Mile Search Radius

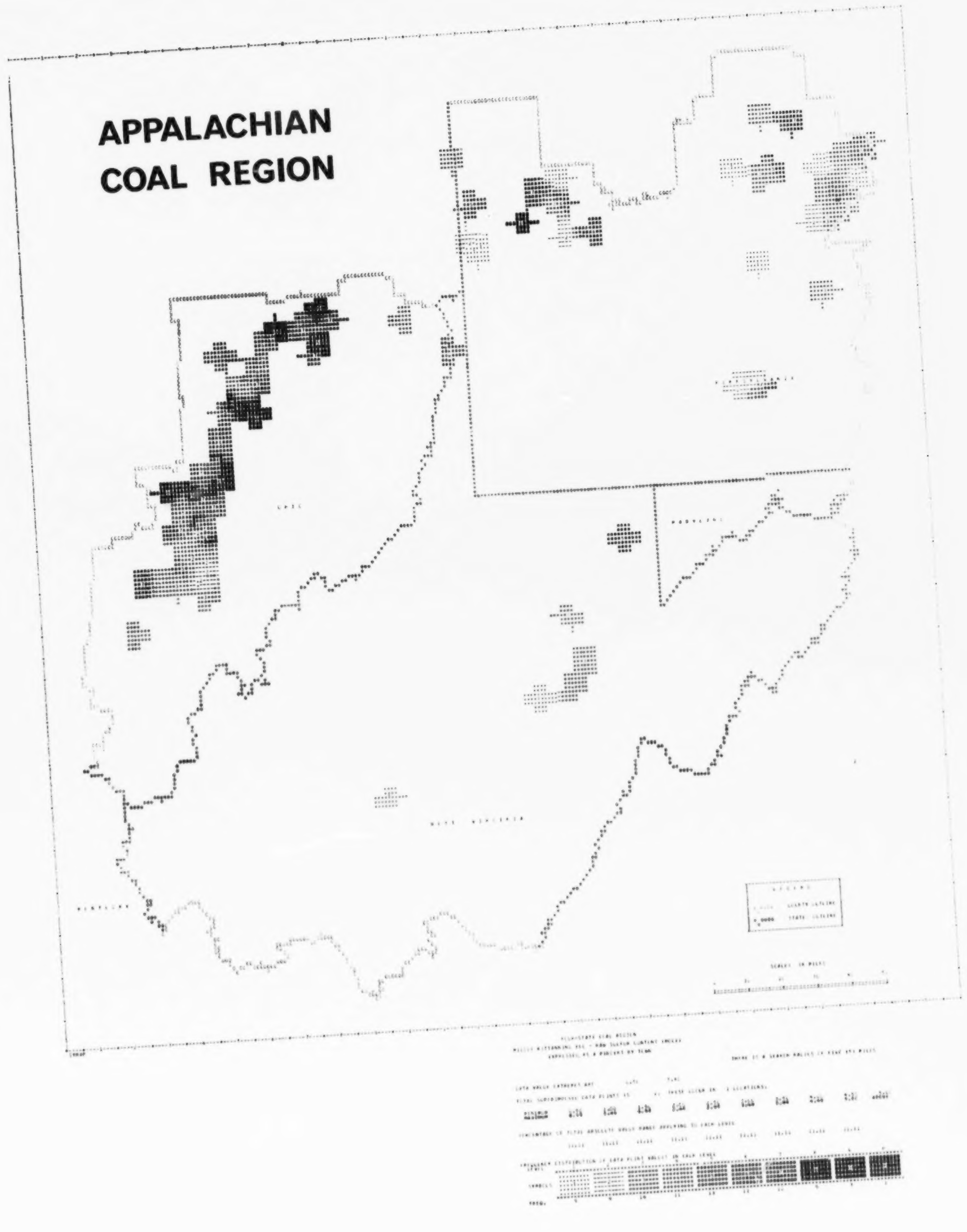


Figure C-3
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
5 Mile Search Radius

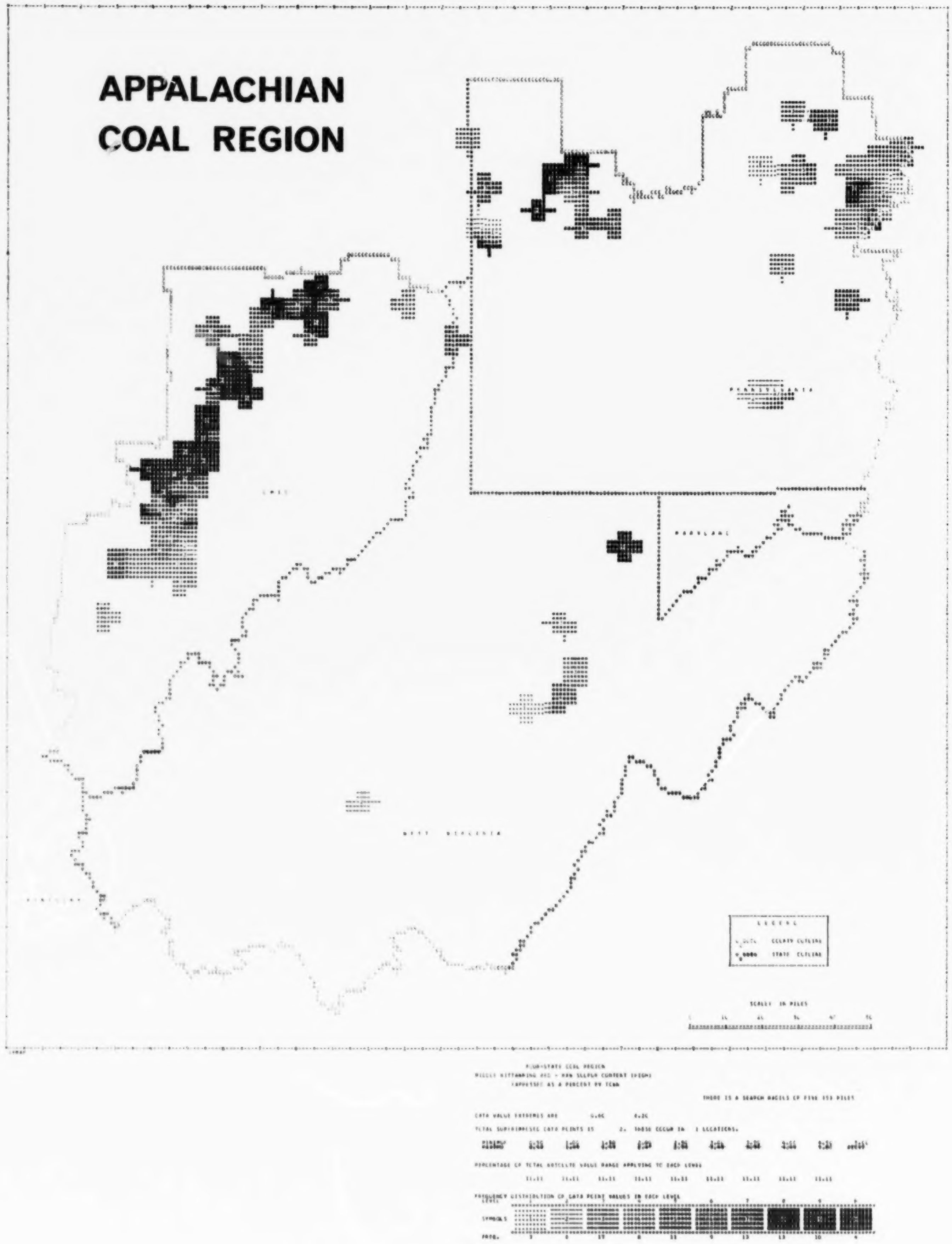

APPALACHIAN
COAL REGION
PENNSYLVANIA
OHIO
MARYLAND
WEST VIRGINIA
KENTUCKY
LEGEND
COUNTY OUTLINE
STATE OUTLINE
SCALE IN MILES
FOUR-STATE COAL REGION
MIDDLE KITTANNING BED - RAW SULFUR CONTENT (HIGH)
EXPRESSED AS A PERCENT BY TOWN
THERE IS A SEARCH RADIUS OF FIVE (5) MILES
DATA VALUE EXTREMES ARE
TOTAL SUPERIMPOSED DATA POINTS IS
THESE OCCUR IN
LOCATIONS.
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL
SYMBOLS
FREQ.

Figure C-4
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
5 Mile Search Radius

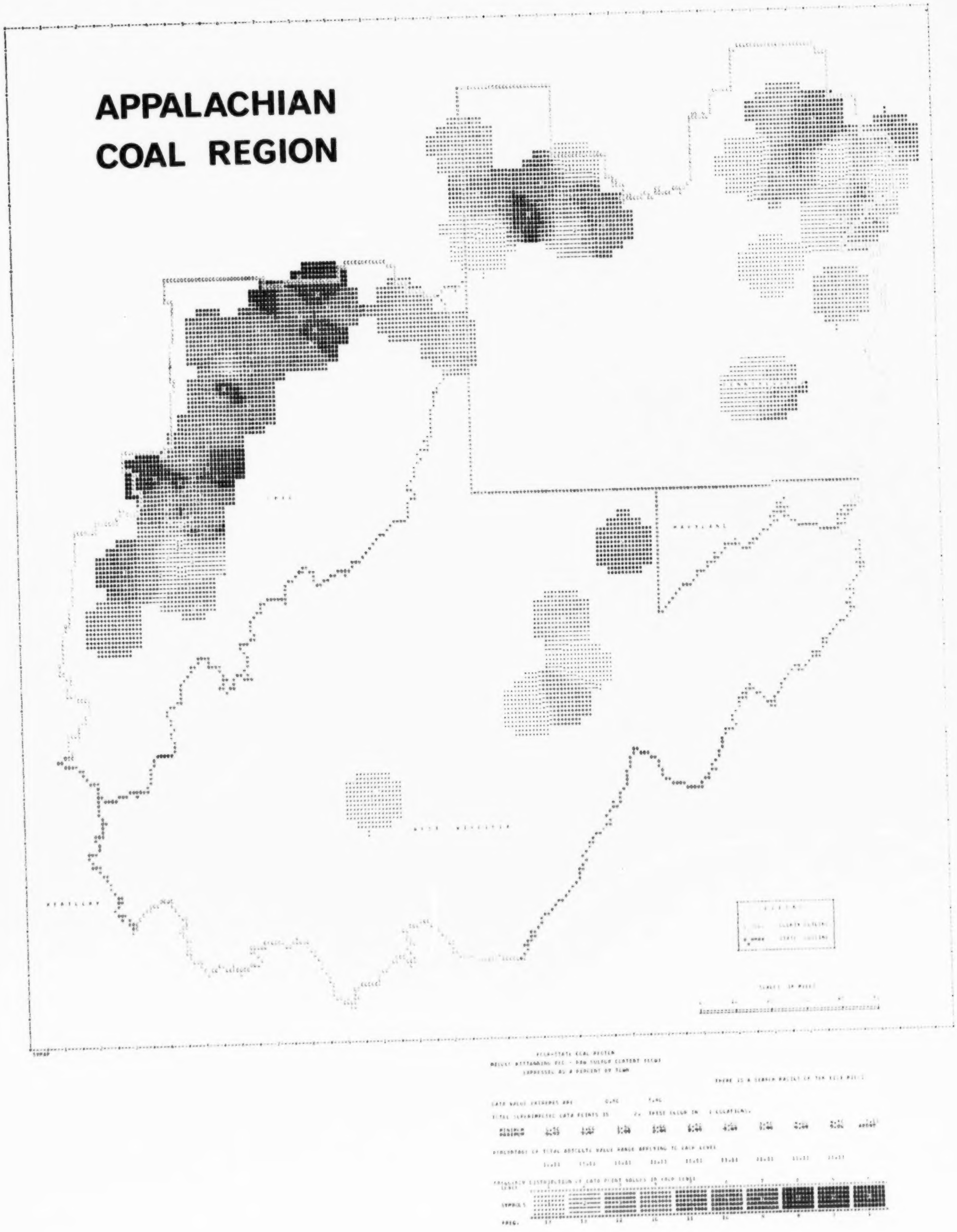


Figure C-5
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Low Values for Raw Samples
10 Mile Search Radius

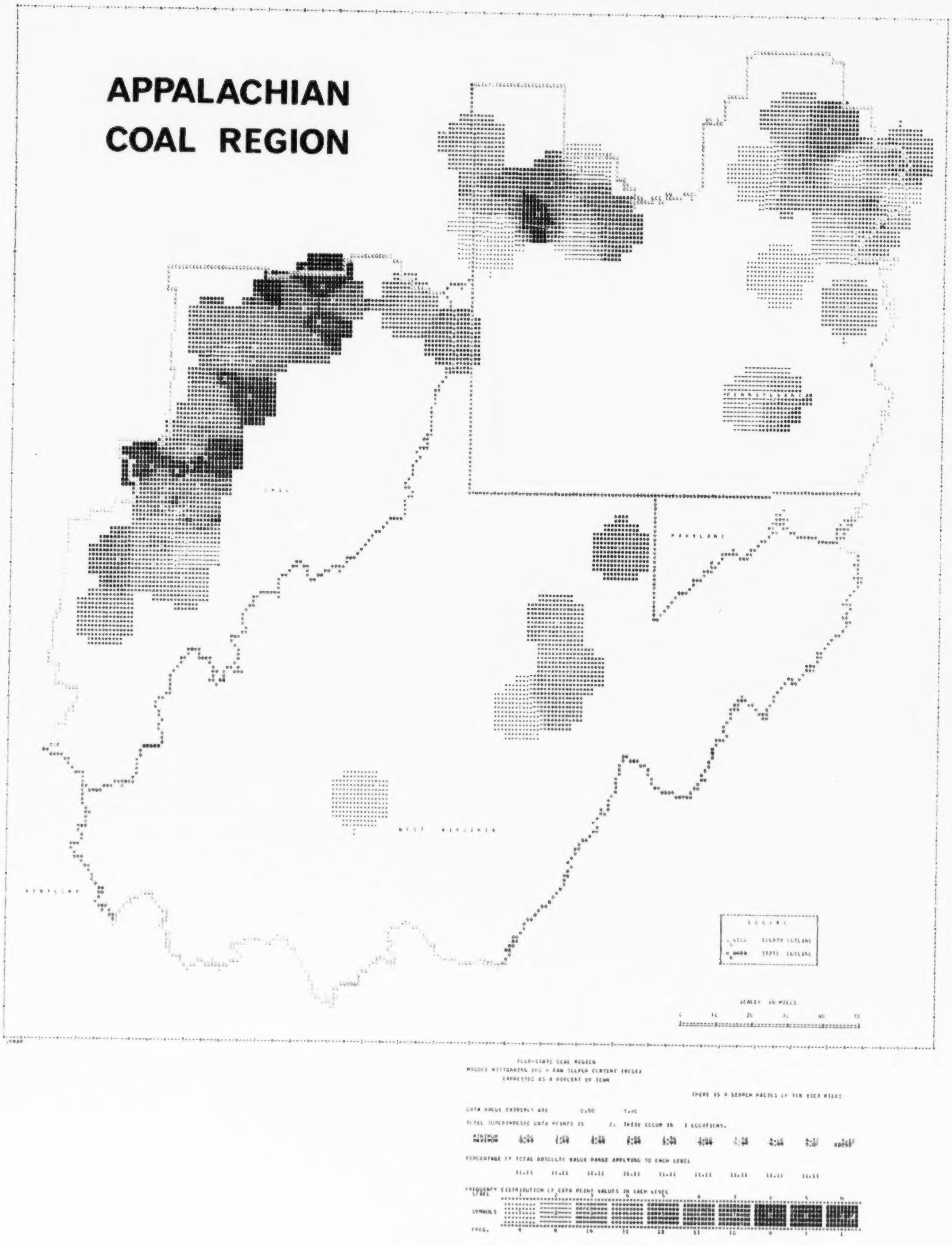


Figure C-6
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
10 Mile Search Radius

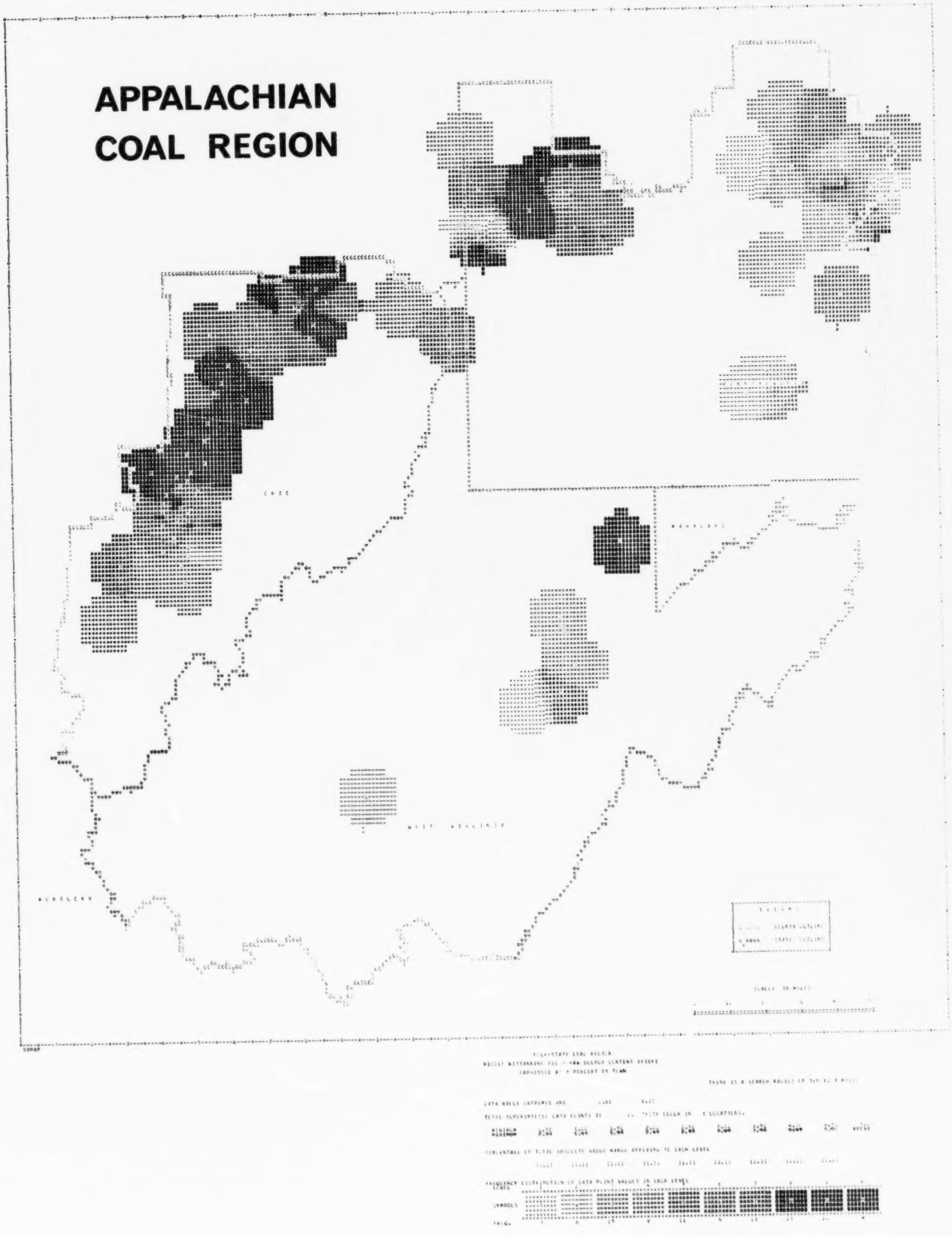


Figure C-7
Middle Kittanning Coal Bed
Sulfur Content Mapped by Towns
High Values for Raw Samples
10 Mile Search Radius

that all but 13 locations have virtually no low sulfur coal as determined by the samples taken.

2.5. MAP SERIES D

Map series D includes: (1) surfaces comparing the mode values for the washed and raw samples for the Pittsburgh Bed as mapped by towns and mapped by counties (Figures D-1 and D-2), and, (2) enlargements of different parts of the study area for the surface of the mode values for raw samples shown in Figures B-10, B-13, and B-17. (Figures D-3 thru D-7).

The values for the interpolated sample surfaces generated from town data points were subtracted from the interpolated surfaces generated from county data points. These surfaces were subtracted at a regular grid interval of about 9/10" or 9 miles on the source map. The new surfaces generated (Figures D-1 and D-2) are subject to considerable error. When we subtract the two surfaces we get a good deal of detail which cannot be trusted except along the eastern, western, and northern edges of the maps where there are more data points on the original surfaces.

In the ideal case, the detail shown on the surface should not be greater than that of the lesser detailed surface from which the map was generated. In this case the detail on the difference surfaces should not be greater than the detail on the map generated from county data points. The town map should be used as a reference surface since it has the best accuracy in the outlying areas and better accuracy than any place on the county map.

Figures D-1 and D-2 show absolute differences in sulfur content from -1.35 to +1.02% for the washed samples and -1.67 to +1.39% for the raw samples. It would have been more informative, in retrospect, to have shown the relative differences by positive and negative ratios. In other words, if at a particular location the town map shows 2% sulfur and the county map shows 1% sulfur, then the value to be mapped on the difference surface would be +0.5, using the town map as the reference surface:

$$Vd = \frac{(Vt - Vc)}{Vt}$$

where: Vd = value on difference surface
Vt = value on town surface
Vc = value on county surface.

The actual values mapped were derived from the equation:

$$Vd = Vt - Vc$$

which would give a value of +1.0% sulfur in this case.

Since we are really concerned with determining what areas have less than 1% sulfur coal and which level of detail we need to adequately show this, an alternative approach could be used:

1) use the town map as the control or reference surface, and,

2) map only those areas of less than 1% sulfur coal shown on the town surface and not on the county surface.

As a refinement the portions of the study area that lack accuracy can be blanked out and only the 'horseshoe' of data points on the town map used as a boundary. This could be accomplished by using the five mile or ten mile search radius areas of Figures B-17 or B-20 as the study area outline for the difference surfaces. There is no easy way to create this new outline with the SYMAP program; a new base map outline package would have to be coded or else the difference maps would have to be generated with the GRID program, as in Phase III.

The changing accuracy of the maps can best be shown by examining the series of maps for the raw Pittsburgh samples by towns in the following order:

1) the base map with data points (Figure B-8)
2) the map with a 5 mile search radius (B-17)
3) the map with a 10 mile search radius (B-20)
4) the map with an unlimited search radius where the entire outcrop area is filled with symbolism (Figure B-10).

As we go through this series of maps we are adding areas with decreasing accuracy. The same approach would be applied to the difference surfaces using the search radius areas from the town data points.

Figure D-3 shows a portion of the surface of mode values for raw samples mapped by towns (Figures B-10 and B-13) enlarged to the scale of the Phase III maps. The same areas of Allegany and Garrett Counties as mapped in Phase III are shown. Figure D-3 can be compared with Figure E-1, one of the base maps for Phase III. In Figure D-3 the line legends for the state and county borders were blown up from the Phase I and II base map while in Figure E-1 these legends were taken directly from the Phase III source map; the accuracy lost by enlarging from the small scale to the large scale is not significant.

When a map is blown up from a small scale to a larger scale, the data points used for all of the smaller scale maps should be shown. Then, the true area used for the interpolation of the larger scale map will be evident and the reliability of the map better understood. Note in Figure D-3 that the bar chart below the map shows the frequency distribution for all data points in the study area, not just those in the portion mapped. The frequency distribution of the ones within the map boundary must be determined by eye and by refering to the base map, Figure B-8:

level 1 = 6 points
level 2 = 2 points
Total = 8 points

It is immediately evident from both maps (the one showing 1/2% isolines of sulfur content, and the one showing the critical isolines of 0.5% and 1.0% sulfur) that this is a low sulfur coal area. By specifying a detailed base map originally, it was possible to blow up this portion of the study area and demonstrate that it was worthy of closer examination, based on the sulfur content of the Pittsburgh bed.

Perhaps the most meaningful maps produced in Phases I and II are Figures D-4 thru D-7. These maps show detailed portions of the study area outlined on the base map, B-15. The "cut-out" region of maps D-4 and D-6 displays the greatest extremes in the value range and in the spacing of data points of the entire study area. Both of these maps appear at the original base map scale of 1:250,000 and thereby show the amount of detail that went into the preparation of the bed outline. One map was created using the regular SYMAP interpolation with an unlimited search radius (D-4) while the other was restricted to a 5 mile search radius (D-6); at this scale the search radius option produces circular shapes, rather than the 'squares' depicted previously.

The upper-right quadrant of each of these maps was blown-up to twice the original size (or, to a 1:125,000 scale) to produce maps D-5 and D-7; this is the only case where maps were produced at a larger scale than the source maps. This particular quadrant was enlarged because (1) it is a large area with the lowest sulfur coal of the entire region and, (2) there is a significant number of data points that are fairly equally spaced. For these reasons the maps are probably the best series of either Phase I or II and convey the most accurate and detailed information, particularly where the five mile search radius was used. Note that in Figures D-6 and D-7 where the search radius has been used as a study area outline, the bed outline has been shown as a line legend for reference. We can now visually compare the extent of the coal bed--based on the bed outline--and the relatively accurate values for sulfur content--based on the search radius from each data point. When our bed outline and data points can be accurately located, we can use the bed outline as a study area boundary but limit interpolation (and symbolism) with a five mile search radius to areas inside the bed outline. For this study area the information on locations did not warrant such a detailed set of criteria.

Even the results attained in this series are somewhat questionable, considering the extreme range in the number of analyses attributed to the data points. Furthermore, this problem is not as severe in this series as it is in the rest of Phases I and II. In maps D-5 and D-7 there is a range of from 1 to 126 analyses per data point with most of the values being near these extremes. The greatest range is found for the complete set of data points in Phase I where the number varies from 1 to 2448. SYMAP does not weight the 1 analysis any differently from the 2448 in the interpolation process; their associated values are treated equally. With such an extreme range in the number of analyses, the resultant maps are somewhat questionable and should be treated with an even greater degree of caution.

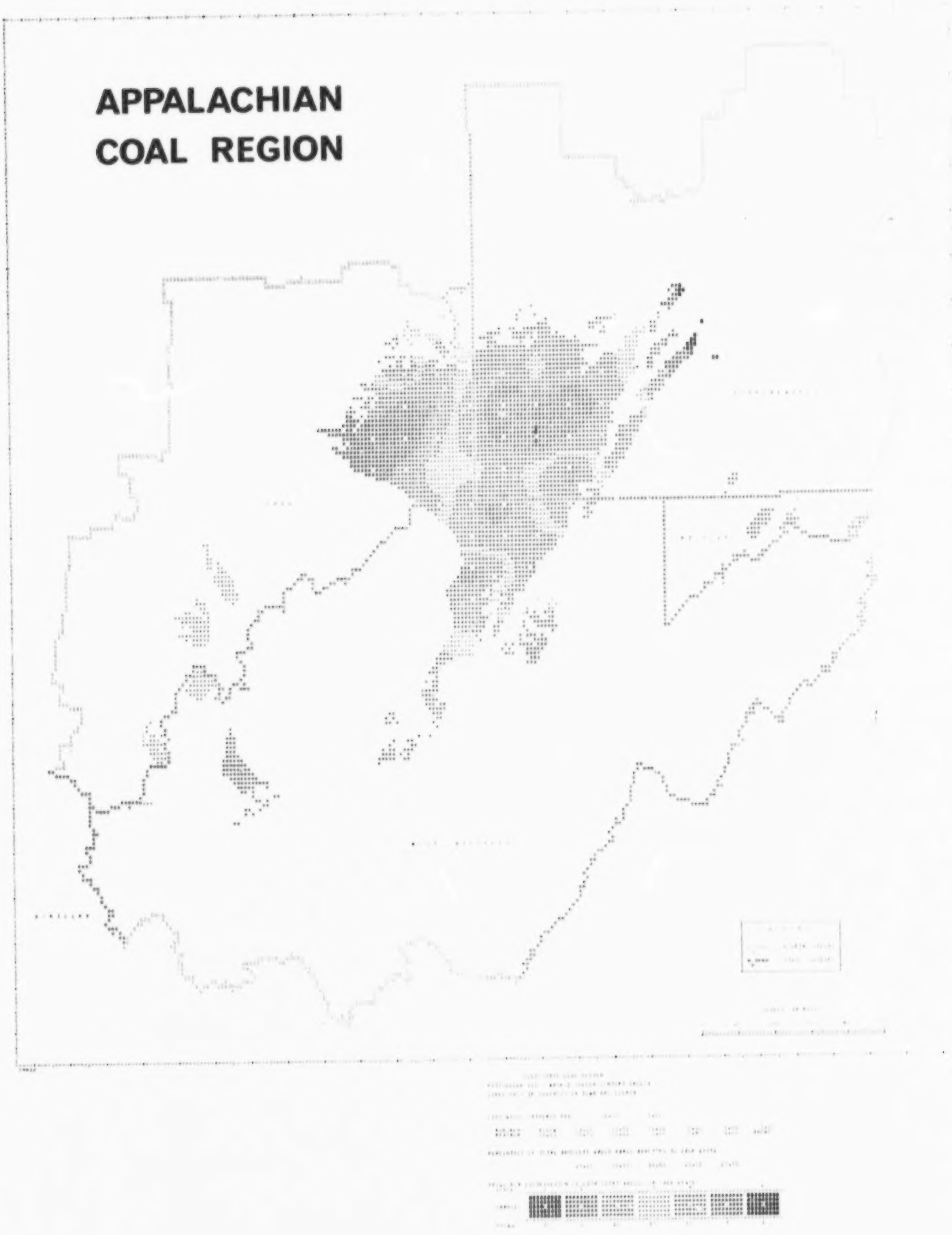


Figure D-1
Pittsburgh Coal Bed
Sulfur Content - Surface Comparison
Mode Values for Washed Samples
Mapped by Counties versus Mapped by Towns

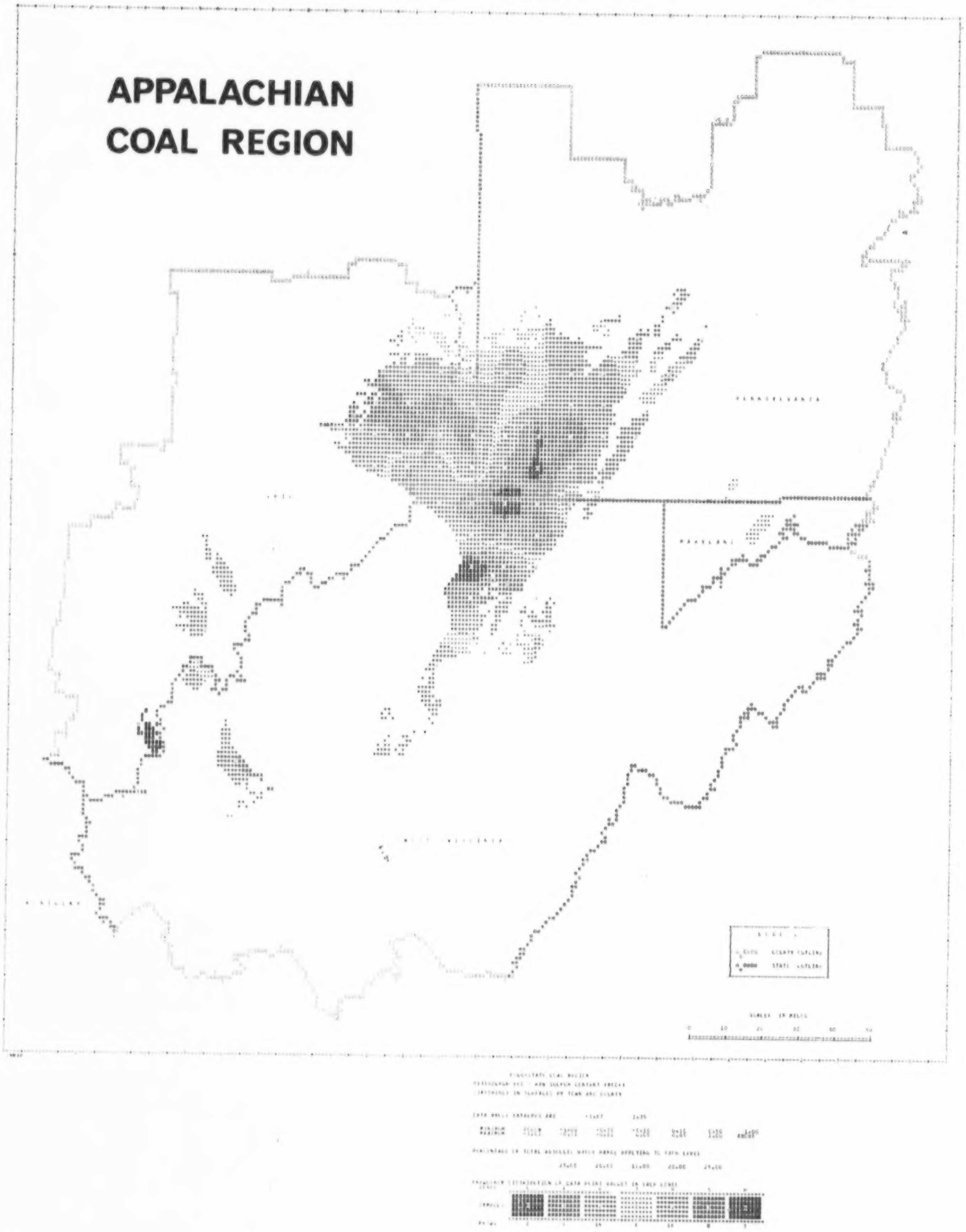
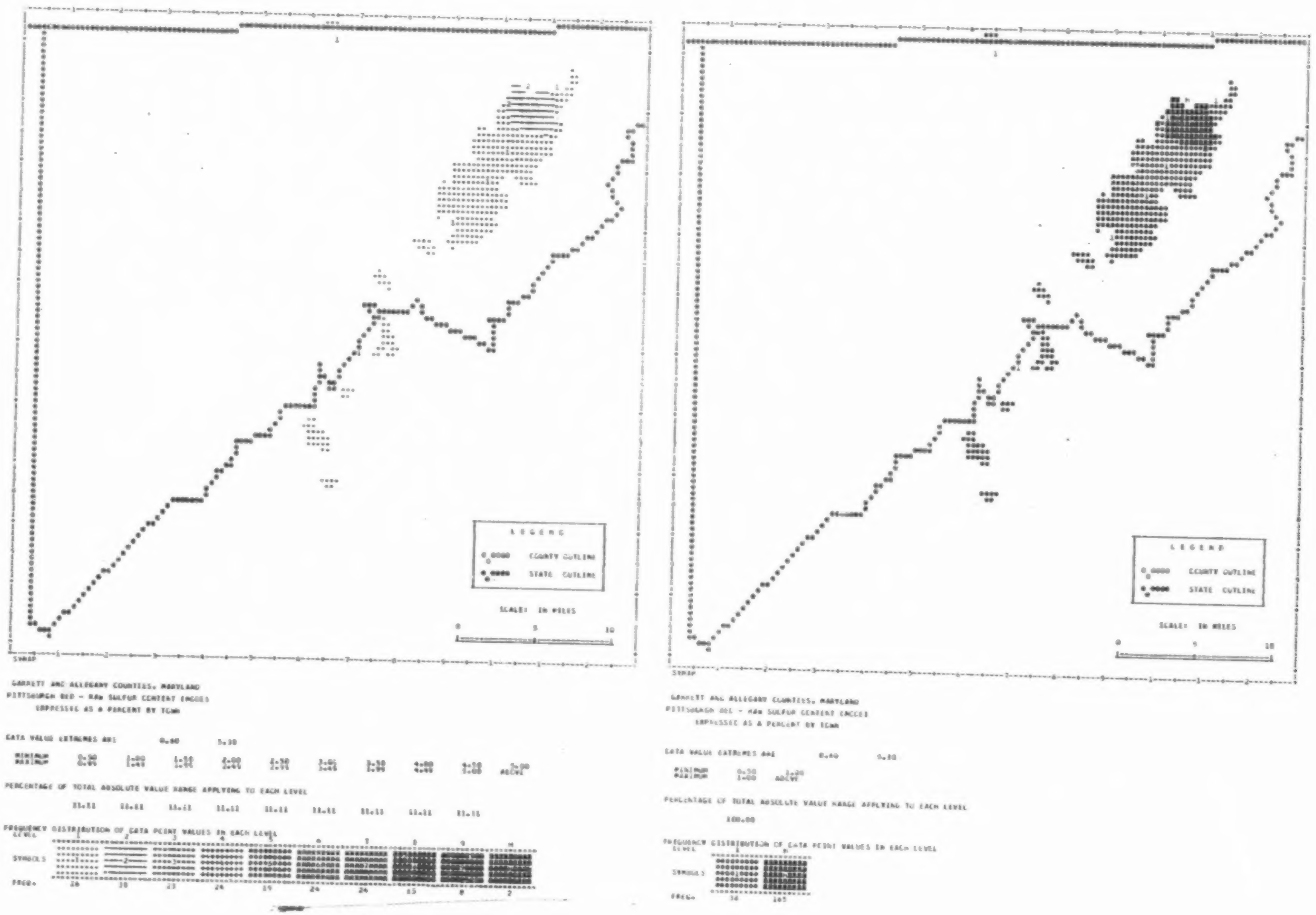


Figure D-2
Pittsburgh Coal Bed
Sulfur Content - Surface Comparison
Mode Values for Raw Samples
Mapped by Counties versus Mapped by Towns



```
GARRETT AND ALLEGANY COUNTIES, MARYLAND
PITTSBURGH BED - RAW SULFUR CONTENT (MODE)
     EXPRESSED AS A PERCENT BY TOWN

DATA VALUE EXTREMES ARE       0.40      5.30

 MINIMUM    0.50   1.00   1.50   2.00   2.50   3.00   3.50   4.00   4.50   5.00
 MAXIMUM    0.99   1.49   1.99   2.49   2.99   3.49   3.99   4.49   5.00  ABOVE

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

           11.11  11.11  11.11  11.11  11.11  11.11  11.11  11.11  11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL        1      2      3      4      5      6      7      8      9      H
 SYMBOLS
 FREQ.       26     30     23     24     19     24     24     15      8      2
```

```
GARRETT AND ALLEGANY COUNTIES, MARYLAND
PITTSBURGH BED - RAW SULFUR CONTENT (MODE)
     EXPRESSED AS A PERCENT BY TOWN

DATA VALUE EXTREMES ARE       0.40      5.30

 MINIMUM    0.50    1.00
 MAXIMUM    1.00   ABOVE

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

           100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL        1      H
 SYMBOLS
 FREQ.       34    165
```

Figure D-3
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
Detail of Allegheny and Garrett Counties

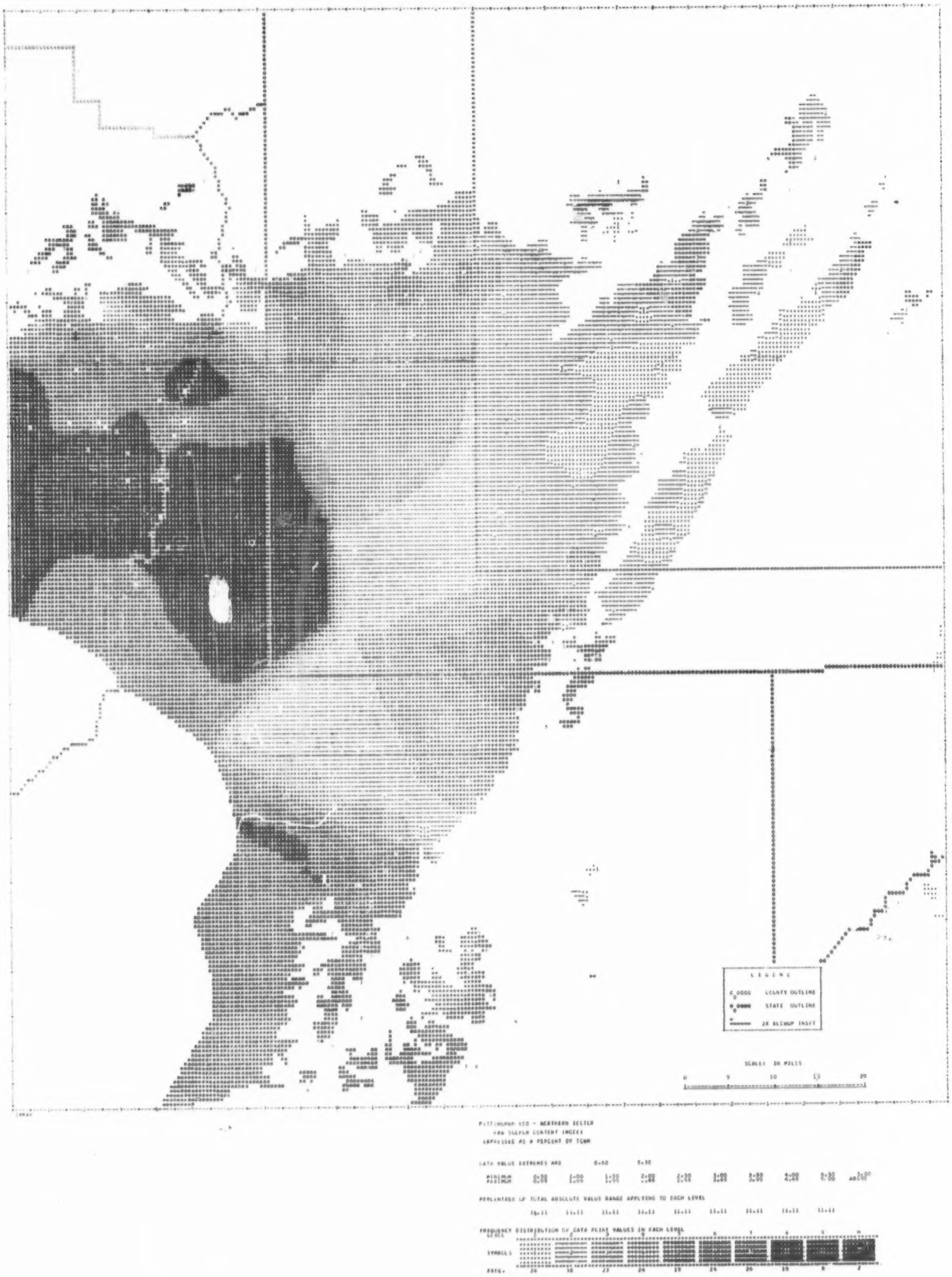

LEGEND
COUNTY OUTLINE
STATE OUTLINE
2X BLOWUP INSET
SCALE: IN MILES
0
5
10
15
20
PITTSBURGH COAL - NORTHERN SECTOR
RAW SULFUR CONTENT (MODE)
EXPRESSED AS A PERCENT BY TOWN
DATA VALUE EXTREMES ARE 0.60 5.30
MINIMUM
MAXIMUM
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11 11.11
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL 1 2 3 4 5 6 7 8 9 10
SYMBOLS
FREQ. 26 30 23 26 19 24 26 19 8 2

Figure D-4
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
Detail of Northern Sector

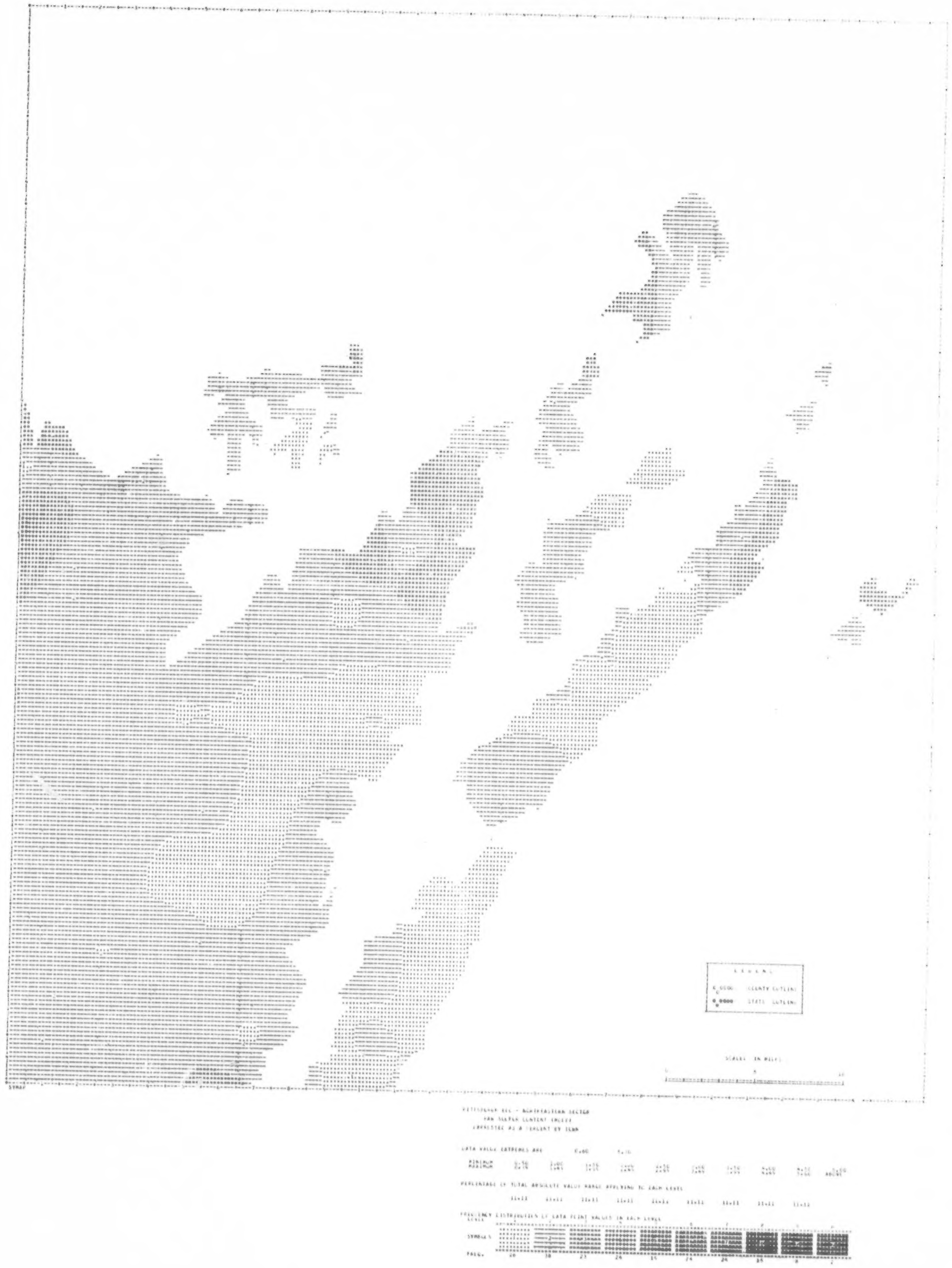


Figure D-5
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
(Blow up of upper right quadrant of D-4)

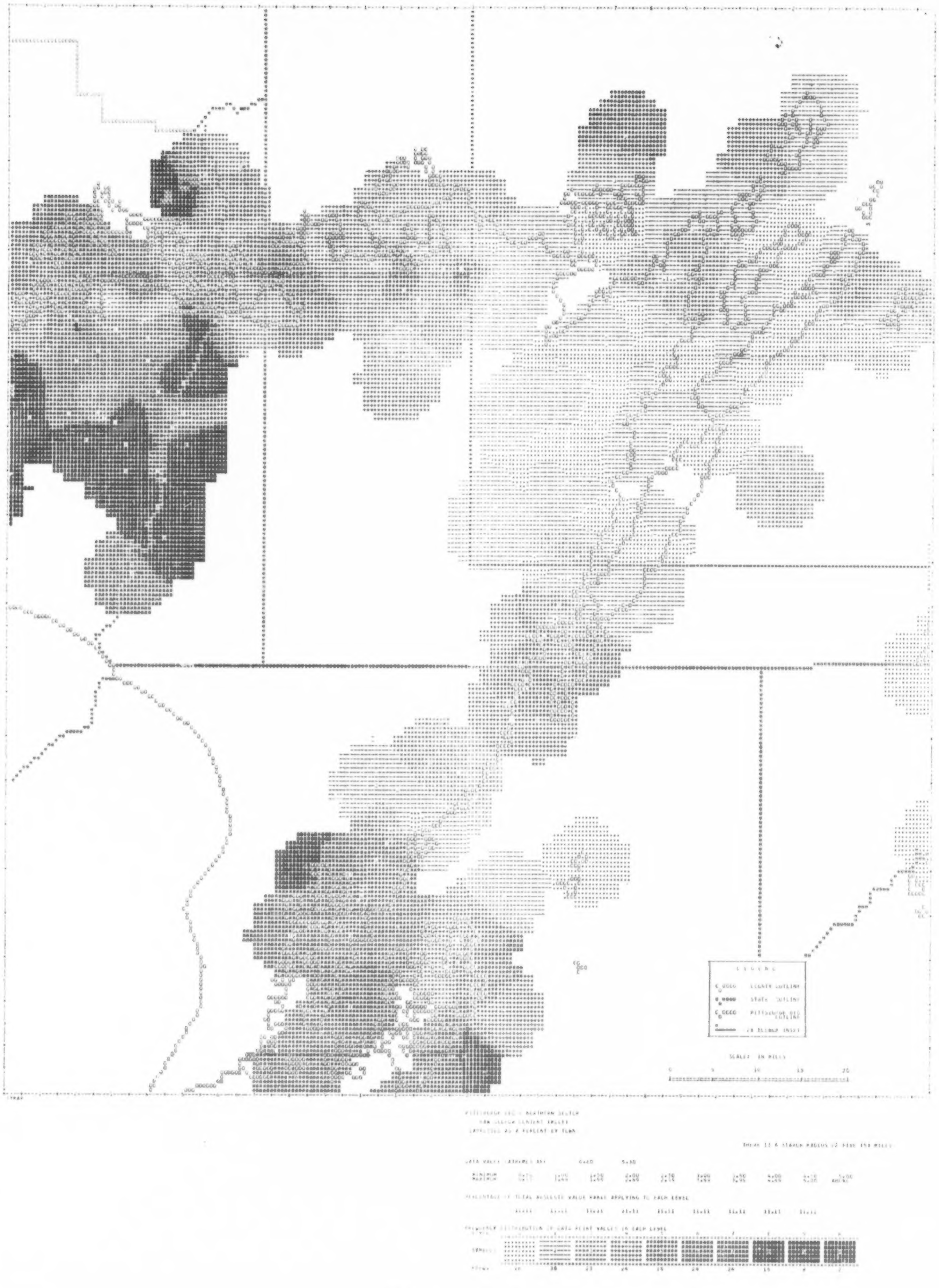


Figure D-6
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
Detail of Northern Sector
5 Mile Search Radius

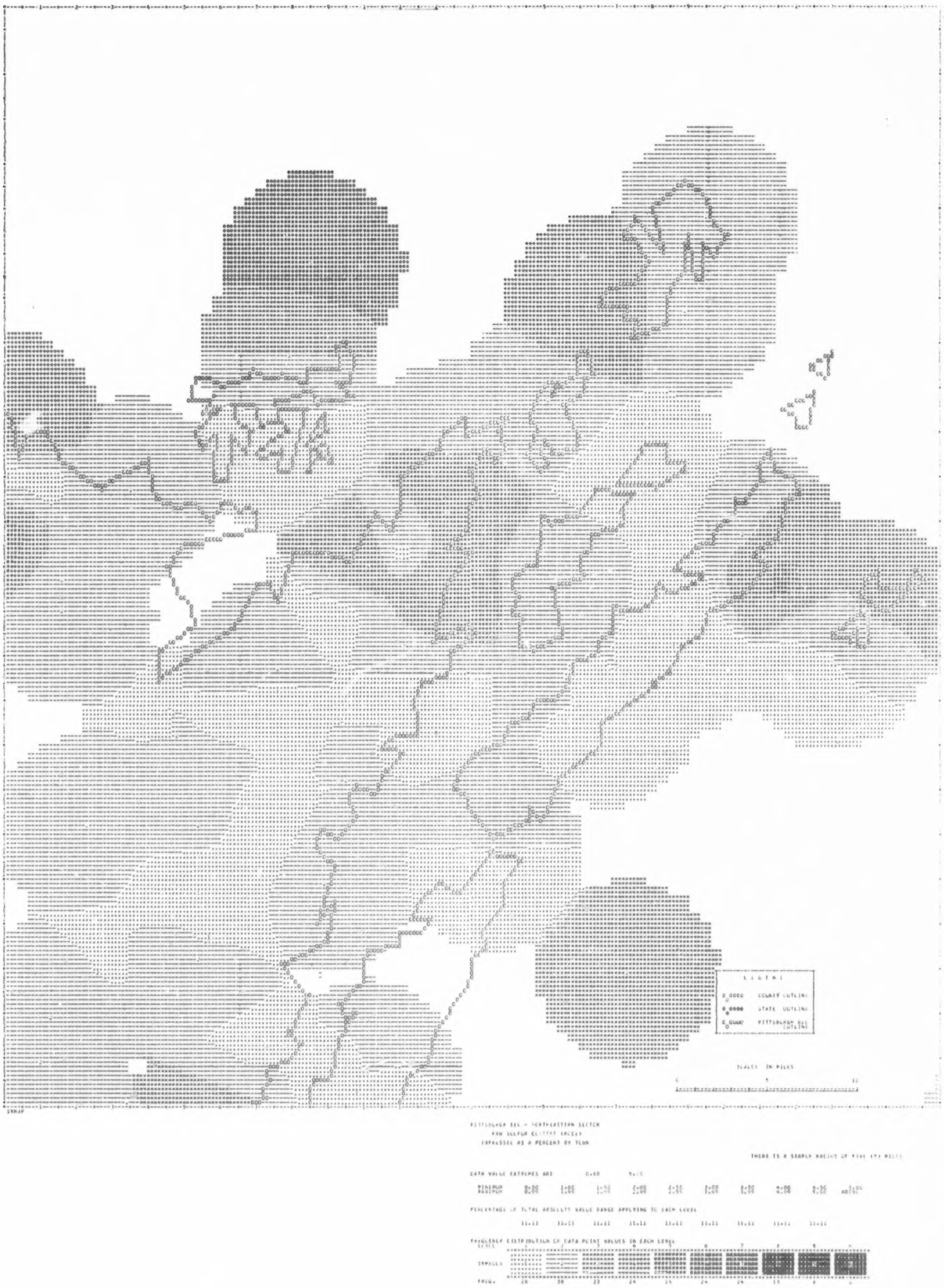


Figure D-7
Pittsburgh Coal Bed
Sulfur Content Mapped by Towns
Mode Values for Raw Samples
(Blow up of upper right quadrant of D-4)
5 Mile Search Radius

2.6. SUMMARY OF PHASE III

The data point locations in Phase III represent actual sampling locations, or best estimates of these locations. For the most part they are no more accurate than the known location of a mine but this is sufficient at the scale of the output maps; if we were to map a smaller scale area--such as one mine property, then we would need to know the core sampling locations and the general origin location for run-of-mine or tipple samples.

Because the data points are actual sample locations unlike Phases I and II, if we assume no error in the data collection or in the positioning of the data points, the contouring can then be interpreted as being more or less accurate, depending on how many data points there are and how far apart they are spread. It is imperative, therefore, to display the data point locations so that the level of accuracy can be clearly ascertained. In no case in Phase III was the number or spacing of data points sufficient to ensure reasonable accuracy, except in the immediate vicinity of data points. In many cases the data points were very clustered or were poorly spaced in relation to the outline of the study area being mapped.

Furthermore, sufficient information was not known about such parameters as the vertical location of samples in a bed to ensure representative data for mapping--variations in sulfur content may be due more to vertical sample location than the horizontal location differences implied by the maps (Gluskoter and Simon, 1968, p. 15). Until sufficient data is available to standardize the samples and remove the effects of parameters other than spatial location, substantive results cannot be obtained.

ALLEGANY AND GARRETT COUNTIES

STAGE ONE	Upper Freeport		Upper Bakerstown		Composite	
Reserves-Mines [raw-levels]	Outcrop	>28"	Outcrop	>28"	Outcrop	>28"
Base	E-1	E-1	E-5	E-5		
Low	E-2	E-2	E-6	E-6	E-9	E-9
Mode	E-3	E-3	E-7	E-7	E-10	E-10
High	E-4	E-4	E-8	E-8	E-11	E-11
[thickness]	F-1	F-1	F-2	F-2		
[quantity] Mode	F-3	F-3	F-4	F-4	F-5	F-5
Three Dimensional Reserves (Mode)	F-6	F-7				
Thickness	F-8	F-9				

UPPER FREEPORT

STAGE TWO	[3/8" Mesh] Outcrop		>28"		[1-1/2" Mesh] Outcrop		>28"		[Comparison] Outcrop		>28"	
	Tot.	Tot.-Pyritic	Tot.	Tot-Pyritic	Tot.	Tot-Pyr.	Tot.	Tot-Pyr.	Tot.	Tot-Pyr.	Tot.	Tot-Pyr.
[Yield-Levels]												
Base	G-1		G-1		G-4	G-4	G-5	G-5	G-6	G-6	G-7	G-7
60%	G-2	G-2	G-3	G-3								
50%			G-8	G-8								
70%			G-9	G-9								
80%			G-10	G-10								
[Quantity]												
60%	H-1	H-1	H-2	H-2								
50%			H-3	H-3								
70%			H-4	H-4								
80%			H-5	H-5								
100%	H-6		H-6									
100-60%	H-7		H-7									

Table II-4
Phase III Maps

2.7. MAP SERIES E

Map series E contains the maps produced in Phase III, Stage One, showing sulfur content for the Upper Freeport and Upper Bakerstown Beds. Maps were produced for both the total outcrop and for the areas over 28" in thickness, using precisely the same data point locations and values in each case. Base maps are shown in Figure E-1 for the Upper Freeport Bed and Figure E-5 for the Upper Bakerstown Bed. In Figure E-1 there are 20 data point locations; only 14 show as black squares on the base map. Of the remainder 2 are superimposed at one location (in the cluster in the upper center) and four occur under the state and county boundary legends. The full set of data points and accompanying information can be shown by running an additional base map with (1) no legends, (2) distinctive symbolism for the superimposed data points, and (3) the number of analyses shown as legends above each point as in Phase I and II. The number of analyses was not shown since out of 20 data points only 7 had more than one analysis and only 4 of these more than 3 analyses. Since the number of data points is also very small we are clearly working with a poor statistical sample.

Of the 20 data points 7 (including the two that are superimposed) are clustered together in one small area; the remaining ones are not well spread out over the study area. The problem is particularly acute when the areas over 28" thick are shown. Of the 16 points not hidden by legends, only 5 fall within the study area boundaries and the major portions of the eastern syncline contain no data points.

For the Upper Freeport bed the original base map contained several other outcrop islands, mainly in the northwestern part of Garrett County. These were eliminated because there were no data points associated with them. This problem did not exist with the Upper Bakerstown base map. The question arose as to the validity of interpolating across the area between the smaller western syncline and larger eastern syncline (see Figure E-1). It is possible with SYMAP to place a barrier to prohibit or inhibit the interpolation when appropriate. Since this area does not have complex geology, we can assume that geologic conditions when the coal beds were laid down were the same for both synclines and that the history since then has been relatively the same. Without any information to the contrary we assumed that there was a single formation which was eroded in the middle to create the gap between the synclines. Therefore, we treated them as one formation and interpolated between synclines without the use of a barrier.

Figure E-5 shows the base maps for the Upper Bakerstown Beds. Of the 7 data points four are shown as black squares (2 of these are clustered in the western syncline), 2 are superimposed (in the upper right corner of the eastern syncline) and 1 is under the state boundary legend in the center of the study area. Only the superimposed points are inside the outline of the area over 28" thick; this reduces the accuracy for this series of maps.

Figures E-2 thru E-4 and E-6 thru E-8 show the low, mode, and high values for sulfur content mapped by mines for the Upper Freeport and Upper Bakerstown Beds, respectively. The data points were located for these particular maps on the basis of geologist's reports at the Bureau of Mines. Locations of a mine are generally no more detailed than the number of miles from a town in a certain compass direction. The location of a sample in the area of the mine is almost never known. A further shortcoming of the data is the lack of information as to where the samples were taken in the bed. Very often the concentration of sulfur is quite high at the top and bottom of the bed but not in the middle. If the samples are taken near the top or the bottom they may give a high sulfur reading when the average value of the coal may be low. Ideally, the data should tell us sample location with a great deal of detail in the x, y, and z directions, where x and y are the spatial location of the sample and z is the sectional location in the bed.

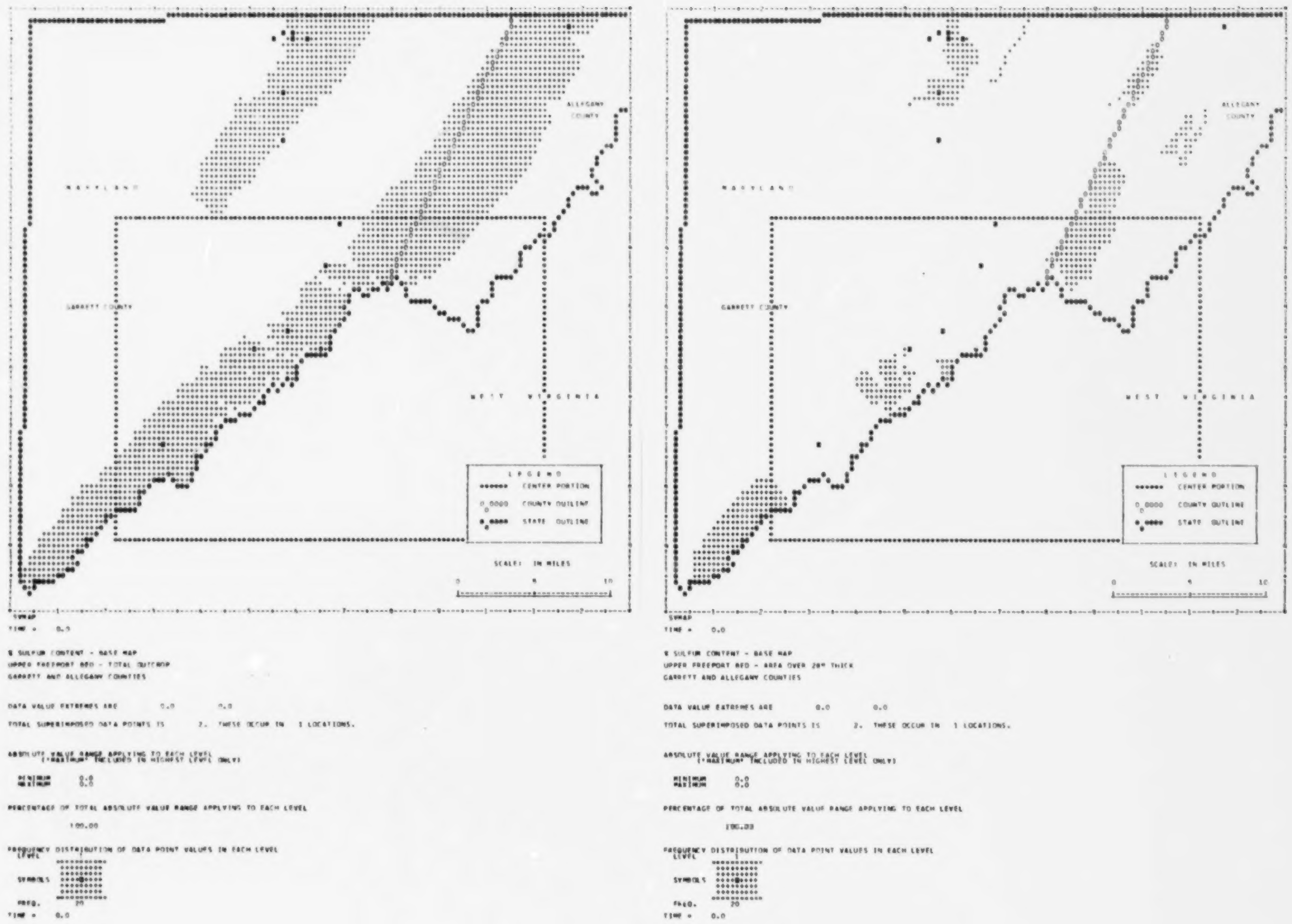
With these shortcomings of the data in mind we can examine the maps of sulfur content. These maps show, in general, that the higher sulfur content coals (by percent) are located near the center of the study area in the Upper Freeport Bed; however, in the Upper Bakerstown Bed the higher concentration tends to be in the southwest section of the study area and the sulfur content decreases towards the center and the northeast section of the bed.

As an example we can examine Figure E-3, the map of mode values for the Upper Freeport Bed. As shown on the base map the eastern syncline has one data point in the very north and several in the middle portion. The interpolation between these displays a gradation from a low concentration of sulfur in the north to a moderate amount in the middle portion of the syncline. The interpolation is affected by the data points in the western syncline. One cannot be certain at all about where the isolines of sulfur content should be. The best one can say is that there seems to be a trend from low concentrations at the study area boundaries to intermediate concentrations toward the middle of the syncline.

In general, one should be very cautious of the extrapolation beyond the data points at the extremes of the region, and of the interpolation between data points which are fairly far apart. The misleading extrapolation is shown in the bottom left hand corner of Figure E-6; the potentially misleading interpolation is evident in the center of the same illustration.

The final set of maps in Series E were composite maps of the sulfur content values for both the Upper Freeport and Upper Bakerstown Beds. These maps combined the A-OUTLINE, B-DATA POINTS nad E-VALUES packages for both the Upper Freeport outcrop and Upper Bakerstown outcrop. Maps were then made which assumed that both beds were part of the same formation. Similar maps were made for the areas over 28" thick, for the low, mode, and high values. (see Figures E-9 thru E-11).

This is really only a mapping exercise: because of the difference in elevation separating the two seams, the composite maps produced are of very little value. They assume that the two beds are fairly close together for mining purposes, which, in fact they are not. They also assume that the two beds are similar enough in geologic



```
 SYMAP
TIME =    0.0

% SULFUR CONTENT - BASE MAP
UPPER FREEPORT BED - TOTAL OUTCROP
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE         0.0         0.0

TOTAL SUPERIMPOSED DATA POINTS IS       2.  THESE OCCUR IN   1 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM      0.0
  MAXIMUM      0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1

  SYMBOLS

  FREQ.        20
TIME =    0.0
```

```
 SYMAP
TIME =    0.0

% SULFUR CONTENT - BASE MAP
UPPER FREEPORT BED - AREA OVER 28" THICK
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE         0.0         0.0

TOTAL SUPERIMPOSED DATA POINTS IS       2.  THESE OCCUR IN   1 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM      0.0
  MAXIMUM      0.0

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             100.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1

  SYMBOLS

  FREQ.        20
TIME =    0.0
```

Figure E-1
Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content Mapped by Mines
Base Map for Raw Samples
left: total outcrop; right: area over 28" thick

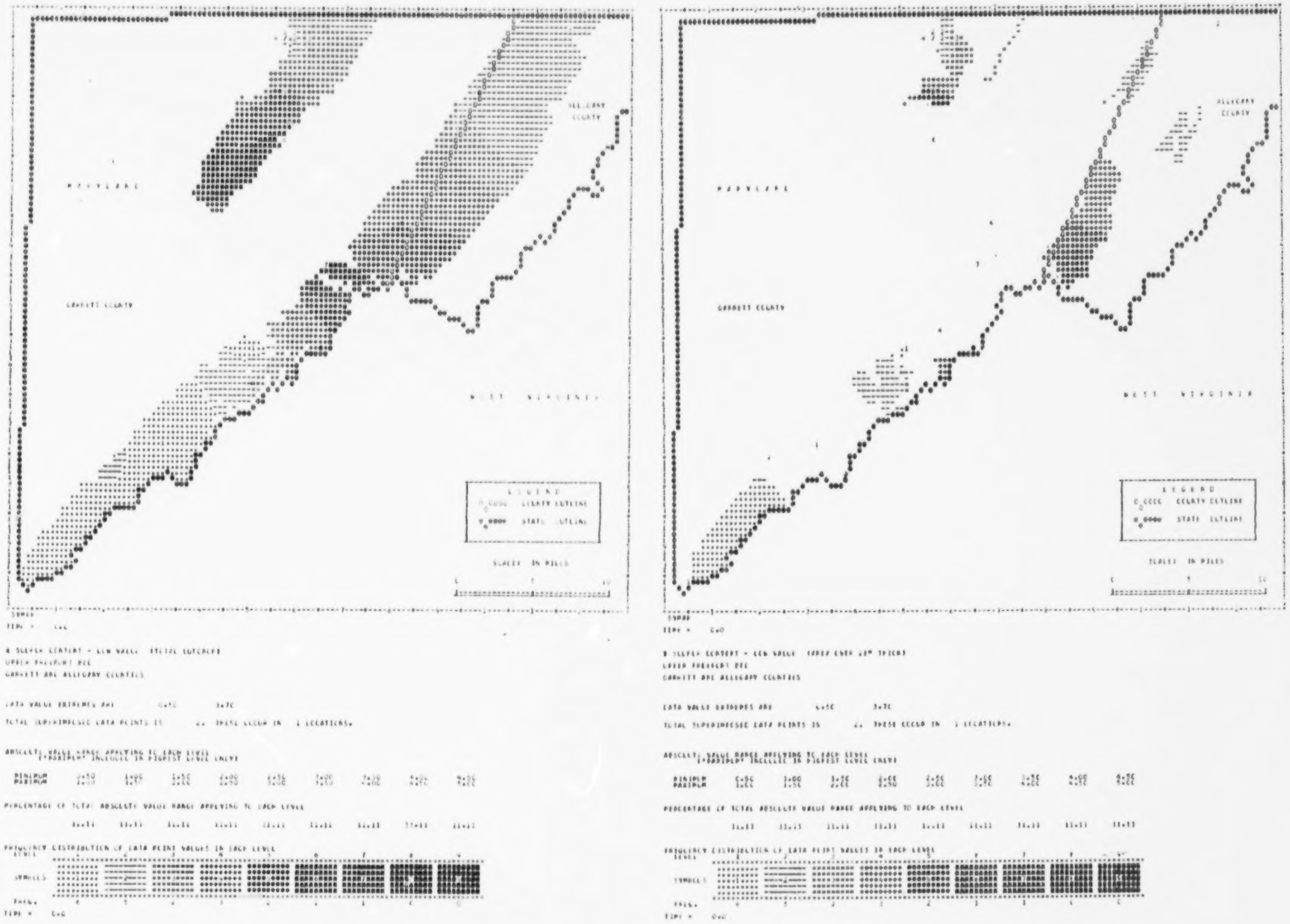


Figure E-2
Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content Mapped by Mines
Low Values for Raw Samples
left: total outcrop; right: area over 28" thick

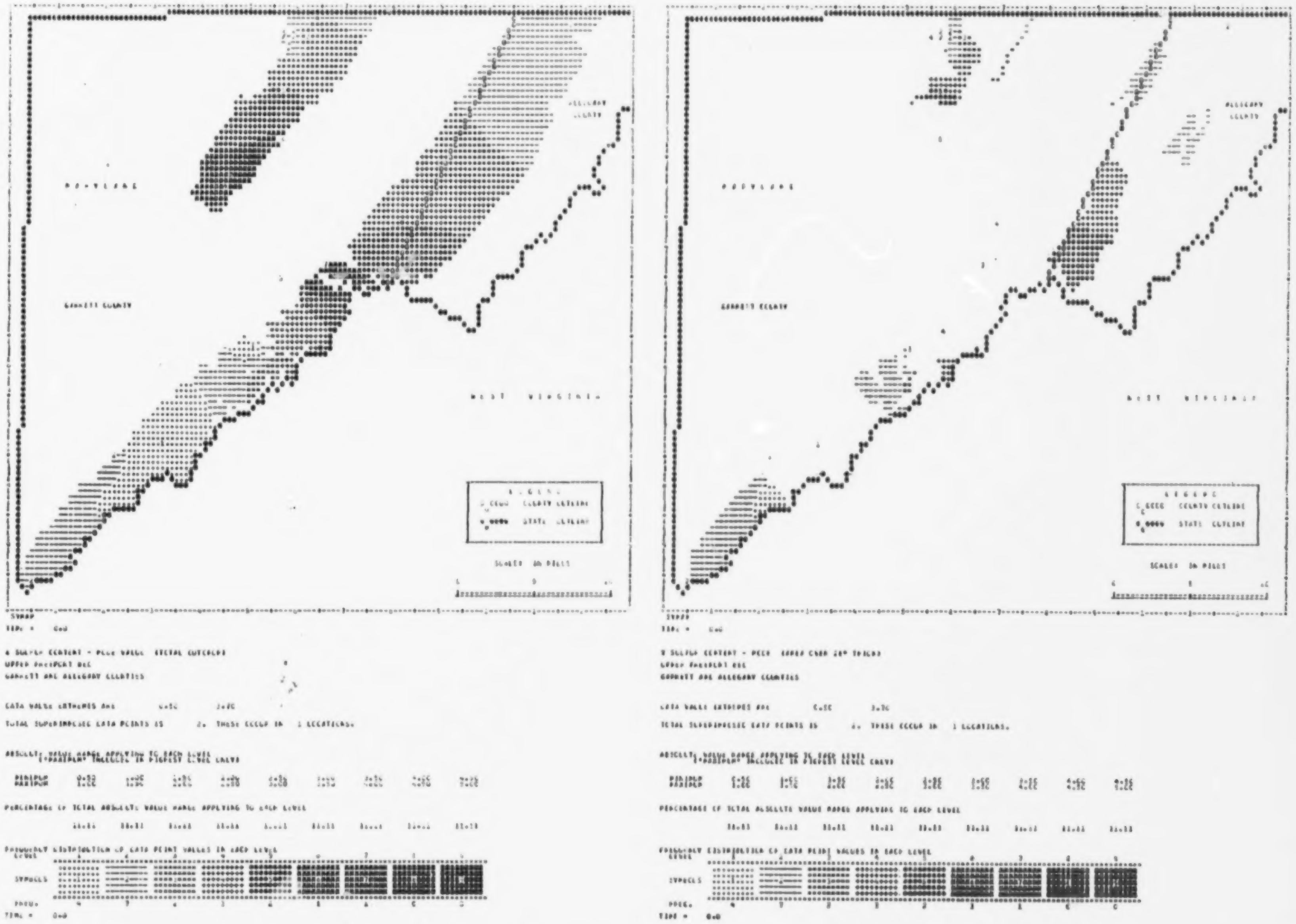


Figure E-3
Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

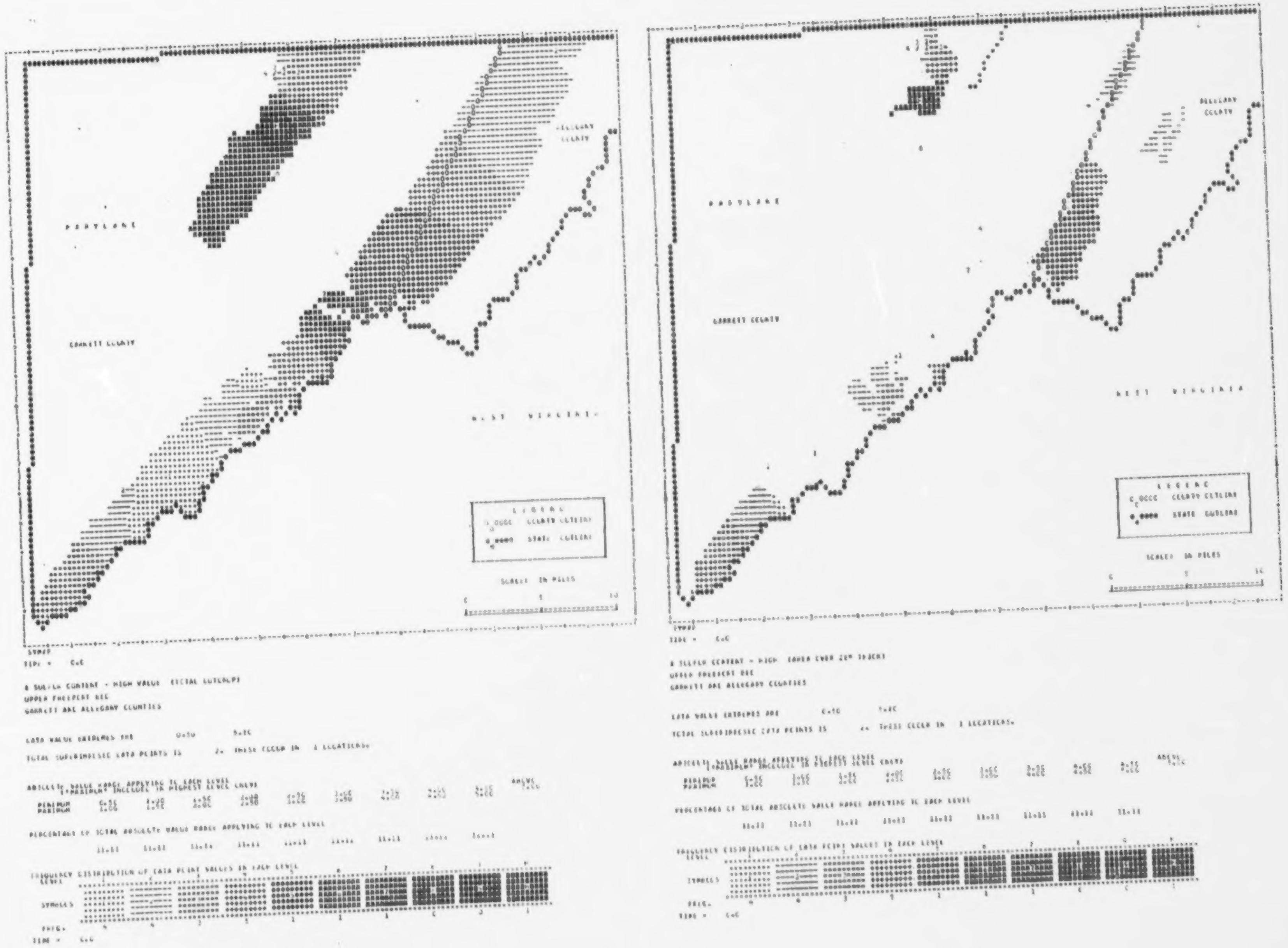


Figure E-4
Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content Mapped by Mines
High Values for Raw Samples
left: total outcrop; right: area over 28" thick

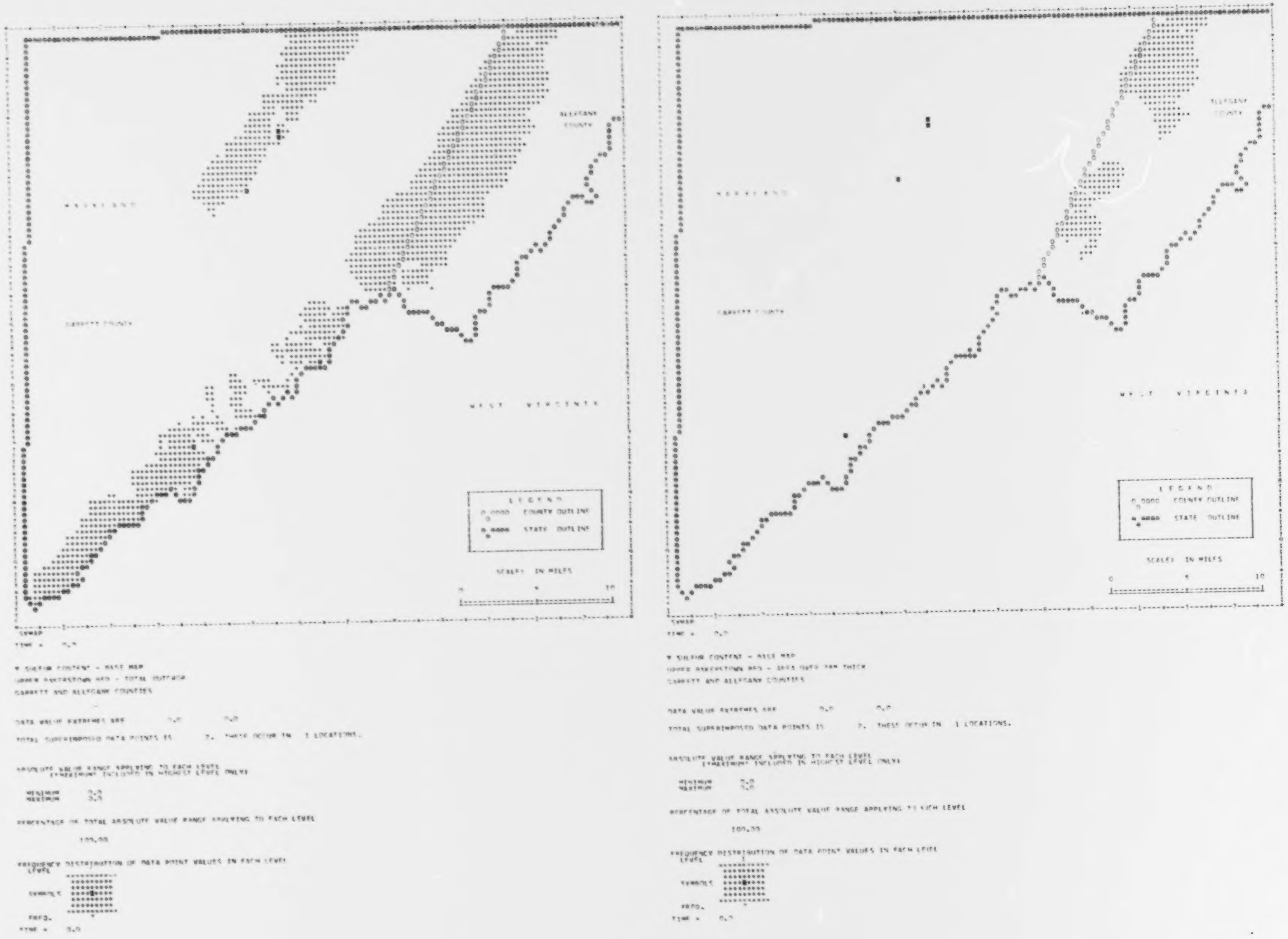


Figure E-5
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Sulfur Content Mapped by Mines
Base Map for Raw Samples
left: total outcrop; right: area over 28" thick

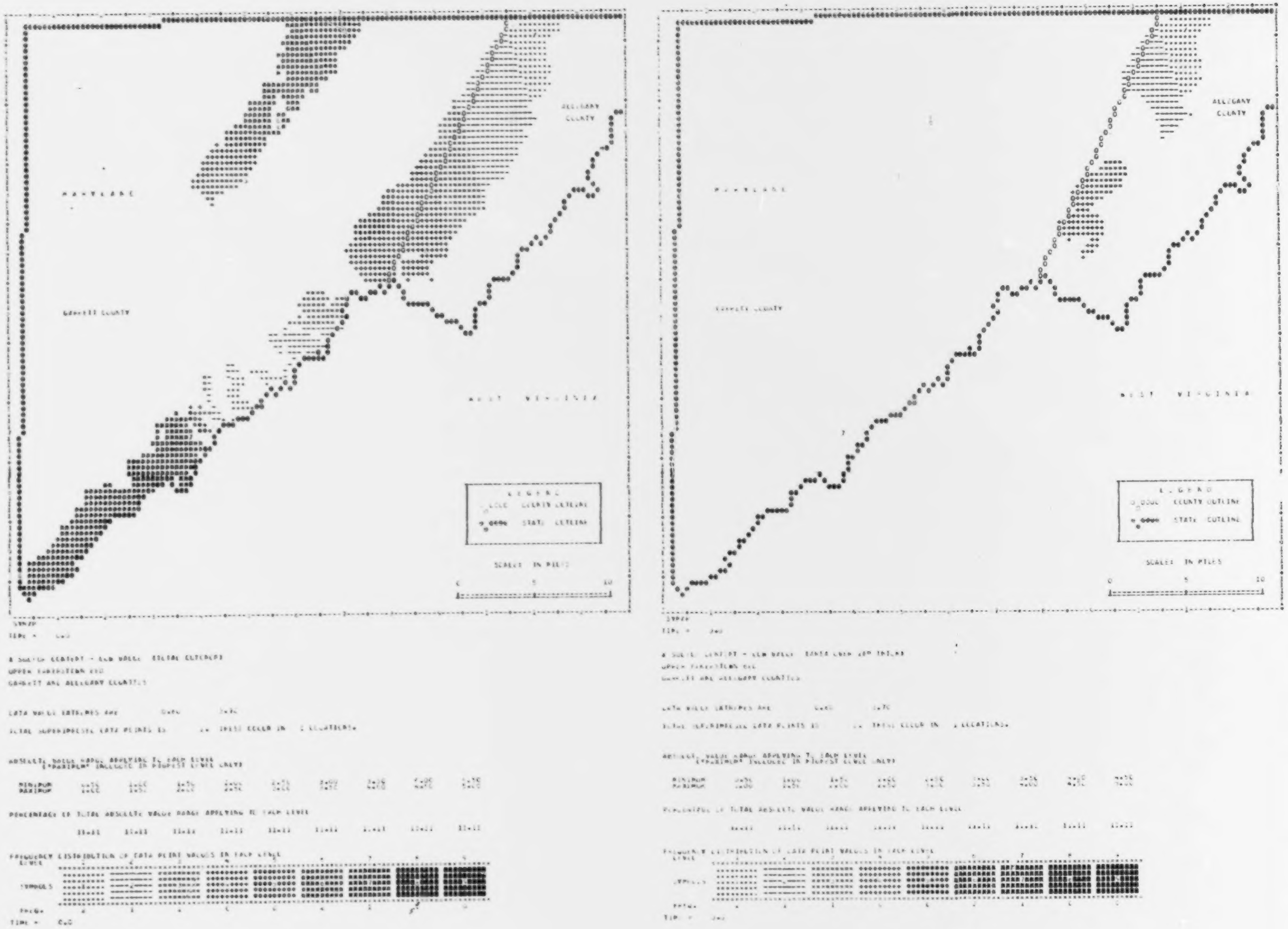


Figure E-6
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Sulfur Content Mapped by Mines
Low Values for Raw Samples
left: total outcrop; right: area over 28" thick

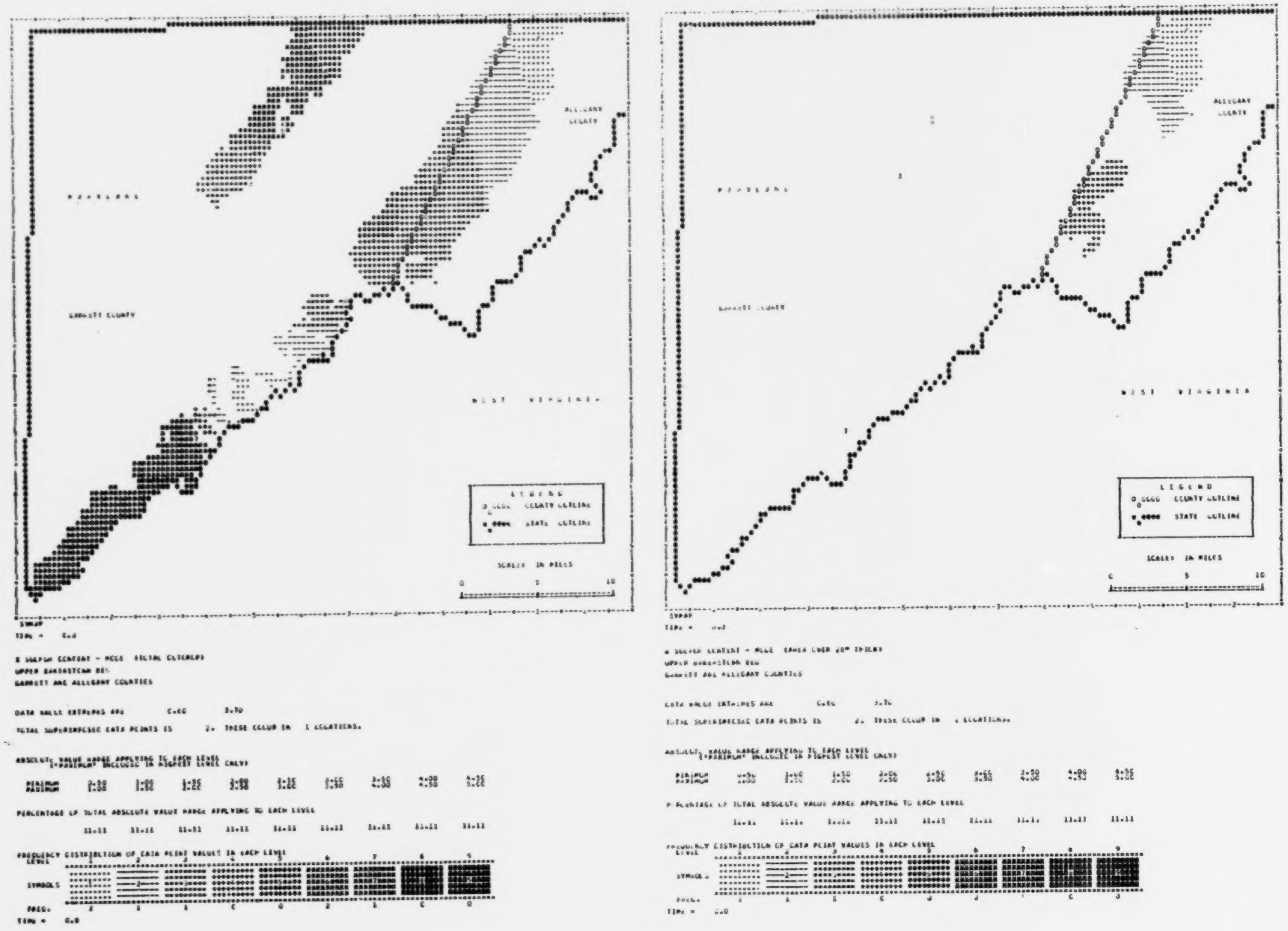


Figure E-7
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

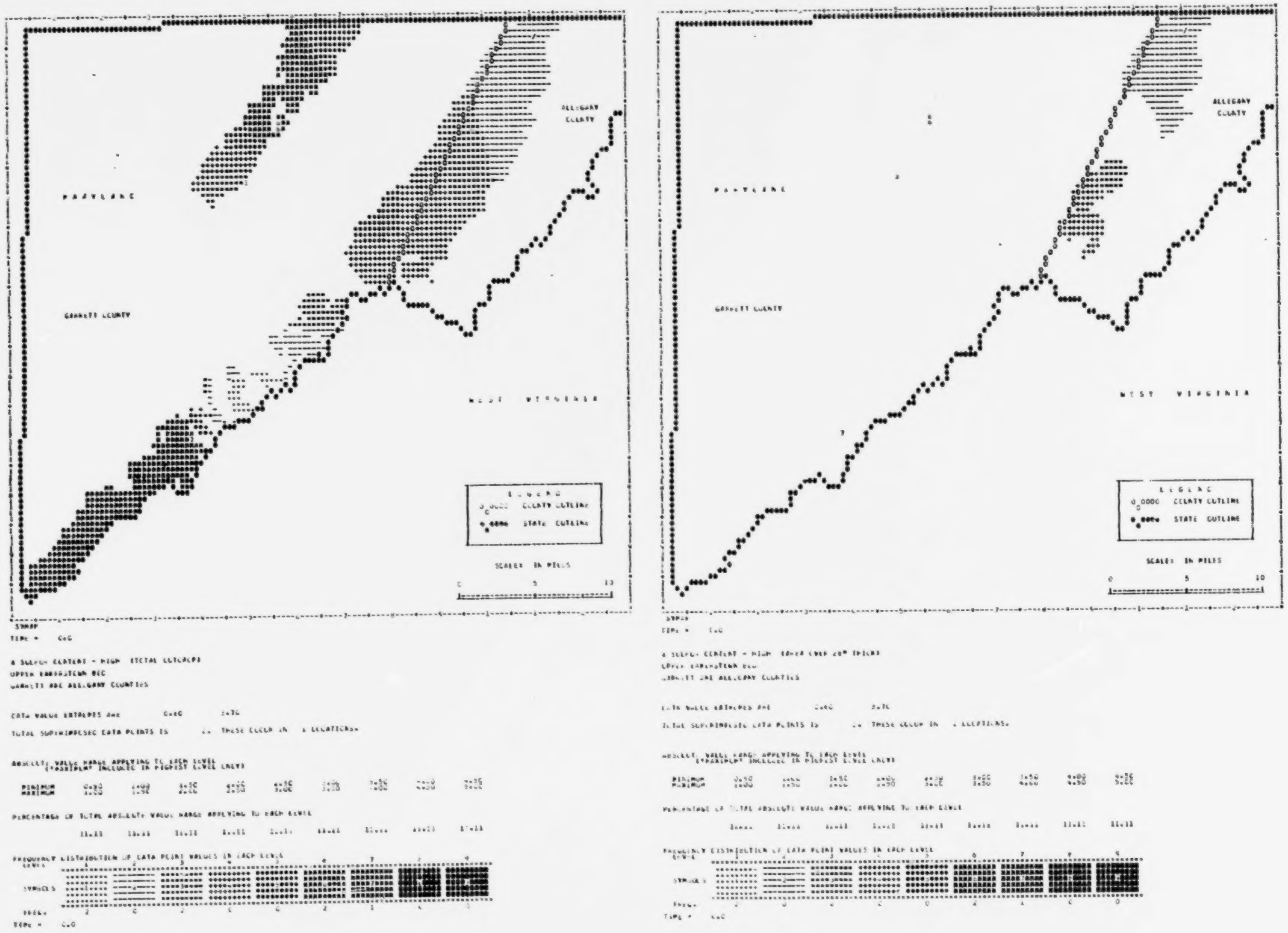
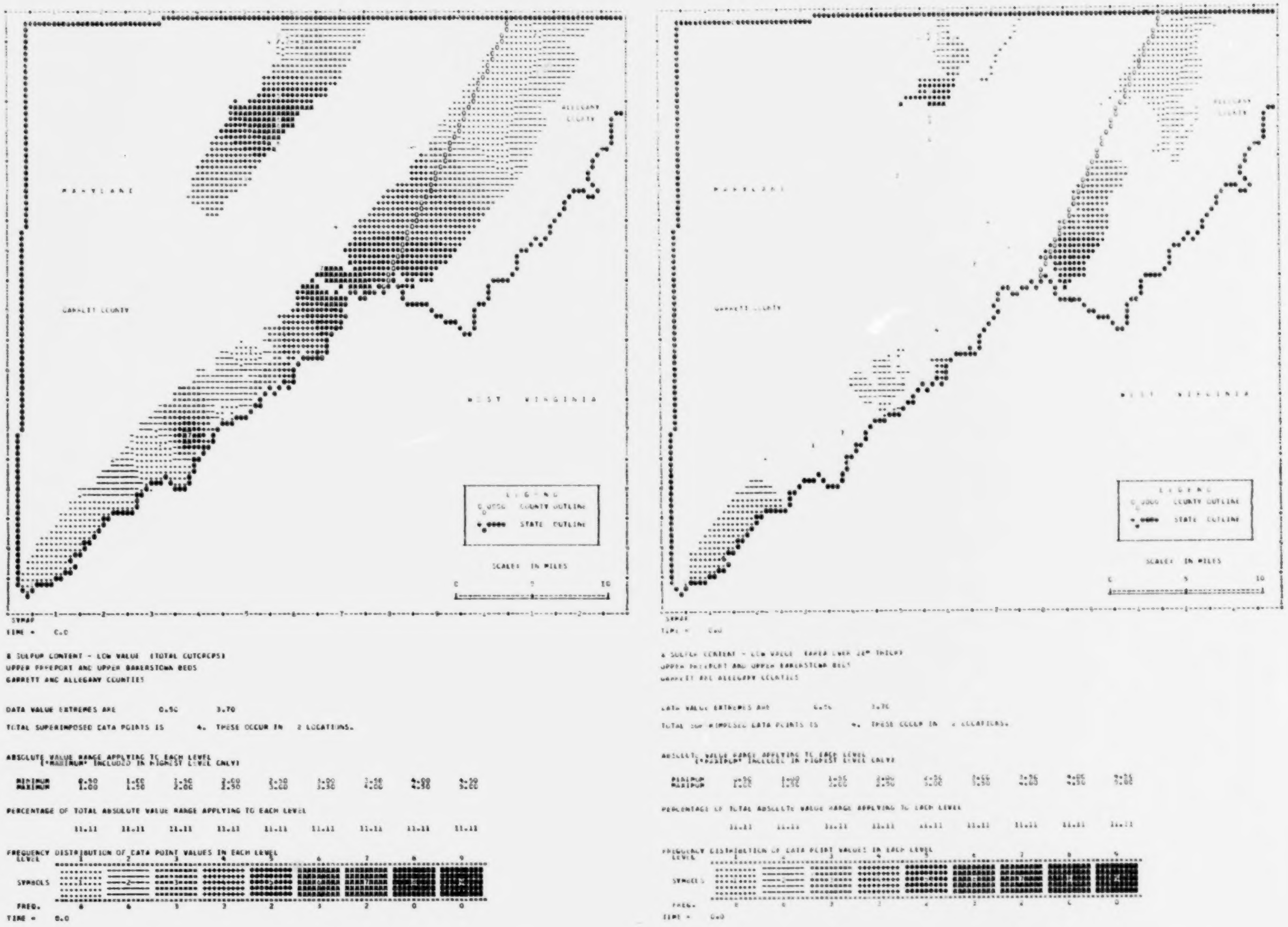
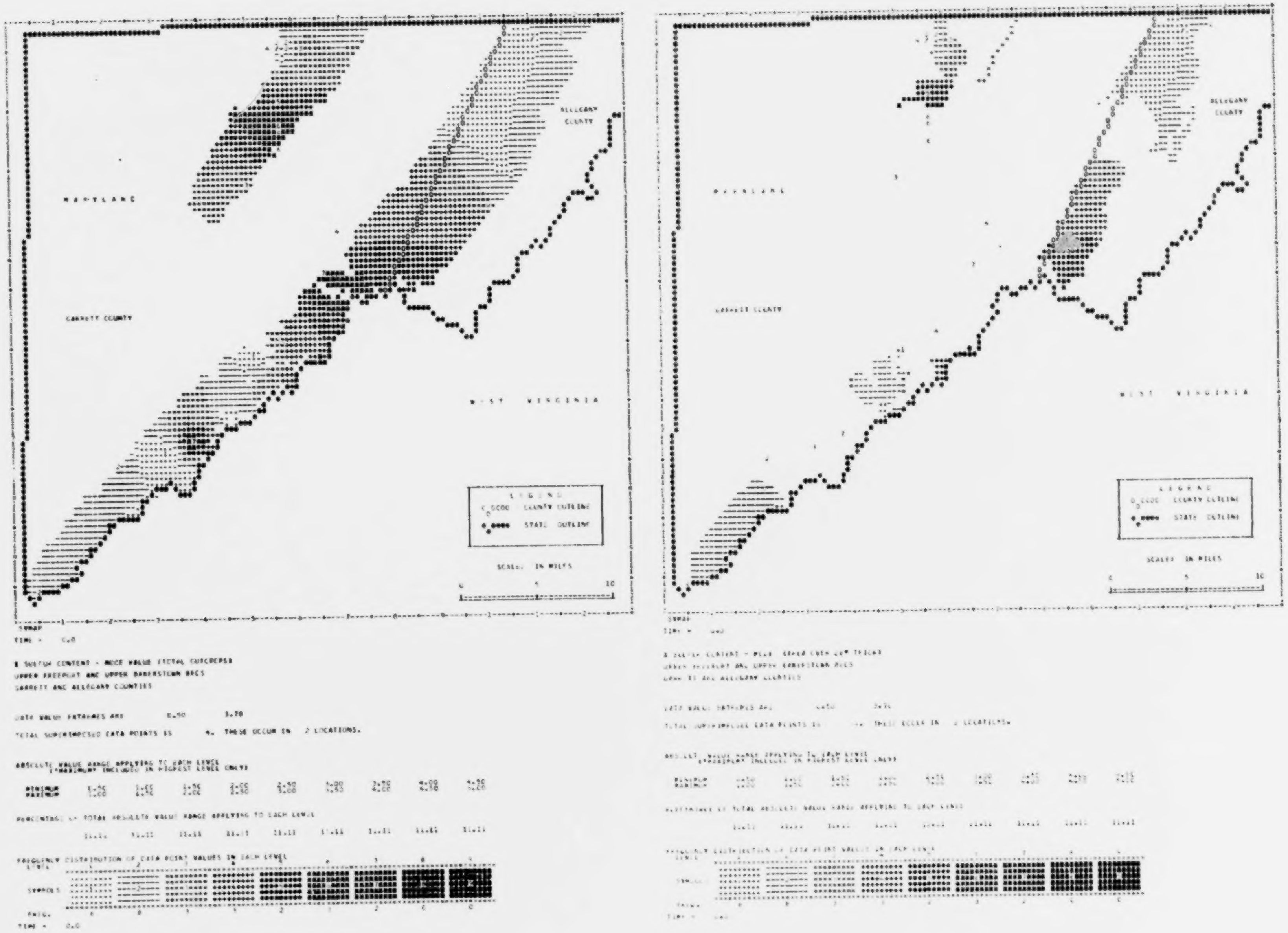


Figure E-8
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Sulfur Content Mapped by Mines
High Values for Raw Samples
left: total outcrop; right: area over 28" thick



```
TIME =    0.0

% SULFUR CONTENT - LOW VALUE  (TOTAL OUTCROPS)
UPPER FREEPORT AND UPPER BAKERSTOWN BEDS
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE        0.50       3.70

TOTAL SUPERIMPOSED DATA POINTS IS       4.  THESE OCCUR IN   2 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM     0.50     1.00     1.50     2.00     2.50     3.00     3.50     4.00     4.50
 MAXIMUM     1.00     1.50     2.00     2.50     3.00     3.50     4.00     4.50     5.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

            11.11    11.11    11.11    11.11    11.11    11.11    11.11    11.11    11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL        1        2        3        4        5        6        7        8        9

 SYMBOLS

 FREQ.        6        6        3        3        2        3        2        0        0
TIME =    0.0
```

Figure E-9
Allegany and Garrett Counties
Composite of Upper Freeport and Upper Bakerstown Coal Beds
Sulfur Content Mapped by Mines
Low Values for Raw Samples
left: total outcrop; right: area over 28" thick



% SULFUR CONTENT - MODE VALUE (TOTAL OUTCROPS)
UPPER FREEPORT AND UPPER BAKERSTOWN BEDS
GARRETT AND ALLEGANY COUNTIES

DATA VALUE EXTREMES ARE 0.50 3.70

TOTAL SUPERIMPOSED DATA POINTS IS 4. THESE OCCUR IN 2 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

Figure E-10
Allegany and Carrett Counties
Composite of Upper Freeport and Upper Bakerstown Coal Beds
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

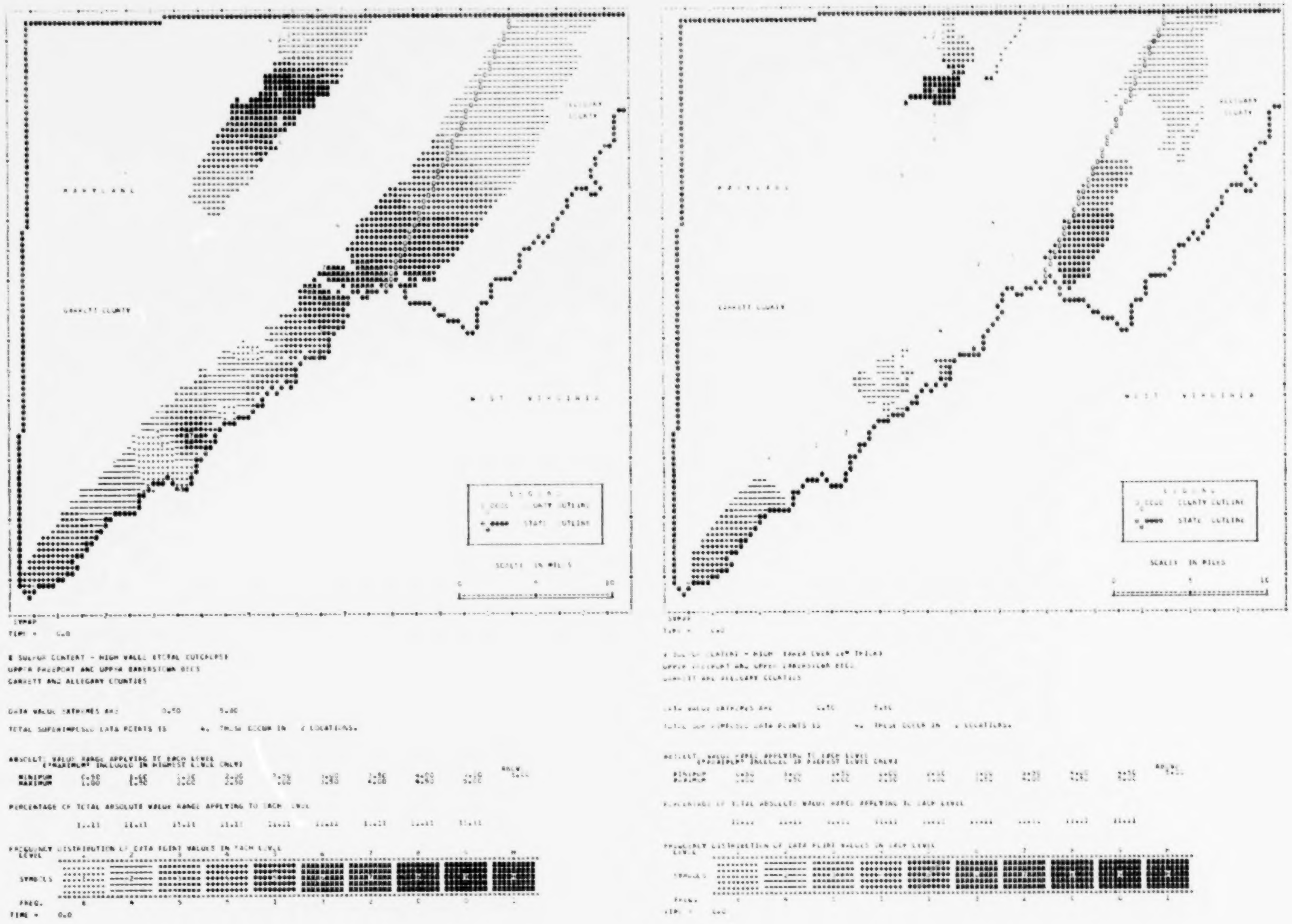


Figure E-11
Allegany and Garrett Counties
Composite of Upper Freeport and Upper Bakerstown Coal Beds
Sulfur Content Mapped by Mines
High Values for Raw Samples
left: total outcrop; right: area over 28" thick

formation and sulfur content that all points can be used together for interpolation; comparing Figures E-3 and E-7 tends to show that this assumption is also probably in error.

If we confine our interpretation solely to the areas surrounding data points, then the composite map can give us a quick and useful overview of any and all low sulfur coal areas for the beds we are interested in. The limiting search radius in conjunction with the outline would be very useful here, particularly for the areas over 28" thick.

2.8. MAP SERIES F

Map series F contains the maps produced in Phase III, Stage One, showing bed thickness and quantity of less than 1% sulfur coal in tons per acre for the Upper Freeport and Upper Bakerstown Beds. Figures F-1 and F-2 show the bed thickness in inches for the Upper Freeport and Upper Bakerstown Beds, respectively; these figures also serve as the base maps for the thickness data. No base map changes are made other than in the location of data points. For the Upper Freeport Bed there are 7 data points, only 4 of which are inside the bed outline. Since the low value of 30" is in the upper center and the high value is in the lower left hand corner, we get a gradual slope from northeast to southwest. This is based on too few data points and too little change in absolute values to be very conclusive.

Major discrepancies are evident when we examine the map of areas over 28" thick in Figure F-1. Although all of our thickness values were over 28", the source maps used indicate only a small portion of the outcrop is actually over 28" thick. It would appear that the thickness data are not representative or complete enough to be meaningful. It may well be that thickness varies considerably on a small scale, particularly in relation to the absolute value ranges found in this set of data. The interpretation of the map in the southwestern portion of the eastern syncline is very much suspect because the data has been extrapolated 15 miles. Likewise in the northern part of this syncline there are no data points; it is the data point in the northern portion of the syncline to the west which greatly determines the values shown in this portion of the eastern syncline.

In summary, only the central portion of the eastern syncline where 3 data points are located can be considered representative and meaningful. This should be kept in mind in examining all of the quantity maps for the Upper Freeport Bed in both Stages One and Two; the quantity in tons per acre is directly proportional to the bed thickness shown in Figure F-1.

The data point locations and their relationship to the Upper Bakerstown outcrop are more reasonable (see Figure F-2) There are considerably more data points describing the thickness of the Upper Bakerstown bed than there were for the Upper Freeport bed; therefore this surface is more representative and meaningful. Only one data point has a value less than 28" thick and this is outside both the outcrop and area over 28" thick outline. Of the 14 locations (16 data points with 3 superimposed at the same location) all but 4 are within the outcrop outline but only 1 is in the area over 28" thick.

This results in a very serious discrepancy between the area defined by the source maps as over 28" thick and the portions of the outcrop found to be over 28" thick according to the data points and values used. This can be explained by one or more of three assumptions:

1) the data base or criteria for "thickness" are different for the Bureau of Mines thickness data and the Boyd report isolines of bed thickness.

2) there are significant errors in one or both of the data bases.

3) thickness varies a great deal locally; therefore, we cannot interpolate a surface from so few points, nor can definitive isolines be drawn as in the Boyd report.

The "coal seam thickness lines" from the Boyd report and accompanying maps and the bed thickness data from the Bureau of Mines do not appear to differ in their criteria; likewise, there is no reason to assume significant errors in either set of data. However, according to the Bureau of Mines the manner in which thickness is measured may vary significantly from location to location and thus introduce errors as well as bias between the two data bases. The third assumption may well explain some of these discrepancies, but there is no way to standardize for the other two.

Figures F-3 and F-4 show the quantity of coal in the ground (in tons per acre) for those parts of the Upper Freeport and Upper Bakerstown Beds, respectively, with less than 1% sulfur coal--based on the mode values for the raw samples. The 'accuracy' of these maps is a function of (1) the maps of sulfur content (Figures E-3 and E-7) and

(2) the maps of bed thickness (Figures F-1 and F-2). As discussed we know that the accuracy of these surfaces from which the quantity is derived is very poor. However, the areas shown in Figures F-3 and F-4 are ones where data point location--and therefore reliability--were much better than average in each of the four original maps (Figures E-3, E-7, F-1 and F-2). These are the first of the maps produced with the GRID program; a separate value is mapped for each cell or computer print position based on the original maps. No interpolation takes place.

Figure F-5 shows the total quantity in tons per acre for the Upper Freeport and Upper Bakerstown Beds combined. It is not a summation of Figures F-3 and F-4; it is derived from the composite sulfur content map (Figure E-10) and the combined thickness (the summation of Figures F-1 and F-2). The significant reservations about all the original surfaces in this case make these maps quantifiably meaningless; however, the approach is very useful if accurate data are available from the original maps and the seams being combined are fairly close together in elevation. Such a map can help locate areas of significant low sulfur coal that would yield a greater total quantity of coal when all mineable seams are considered. Ideally, we would include another variable: overburden, so that the economics of mining could be included.

Figures F-6 thru F-8 are three-dimensional views of surfaces produced with SYMVU for sulfur content and bed thickness for the Upper Freeport Bed. Figures 6a and 6b show two views of the total outcrop for the mode values of sulfur; Figures 7a and 7b show the same values

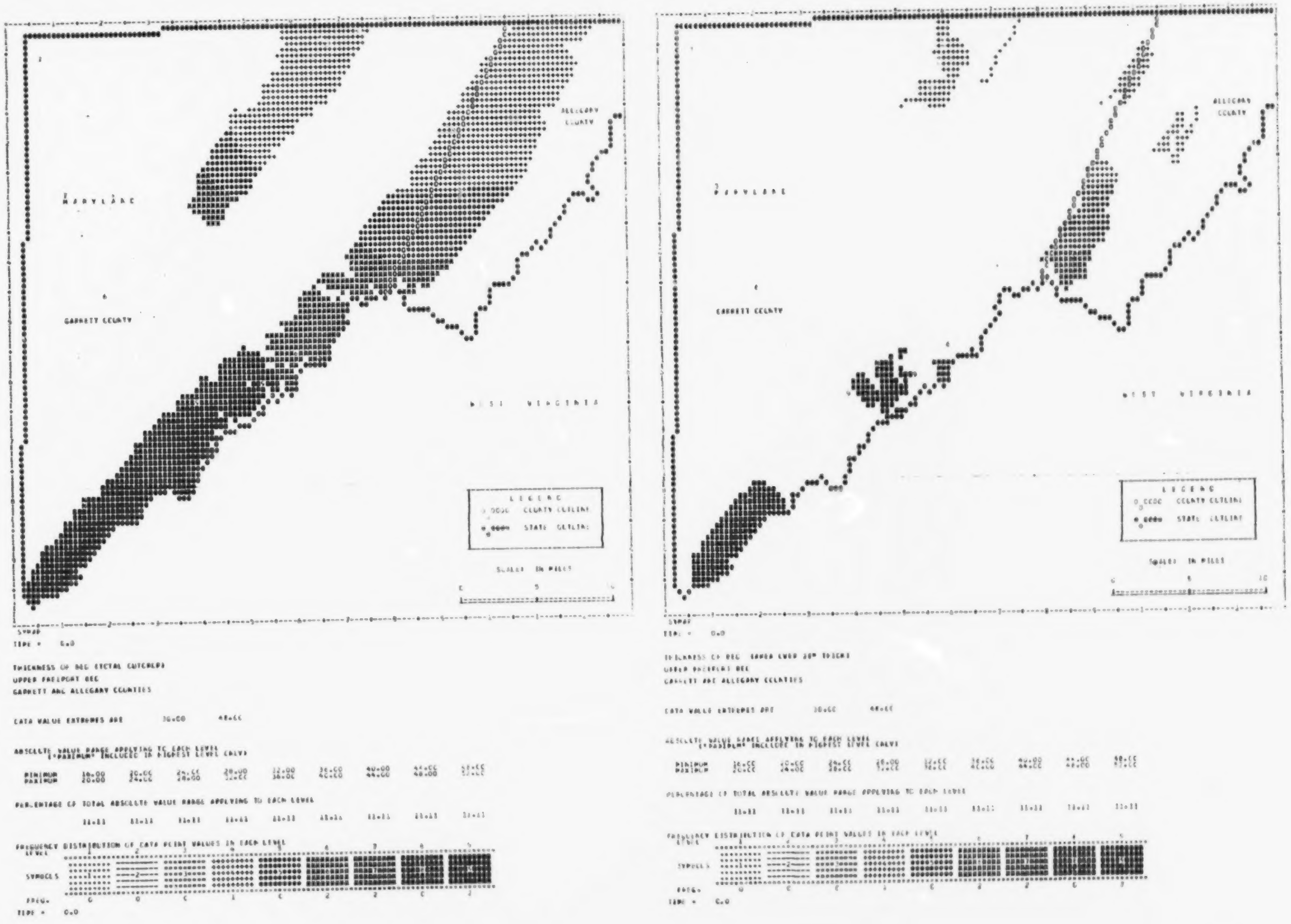


Figure F-1
Allegany and Garrett Counties
Upper Freeport Coal Bed
Thickness of Bed
left: total outcrop; right: area over 28" thick

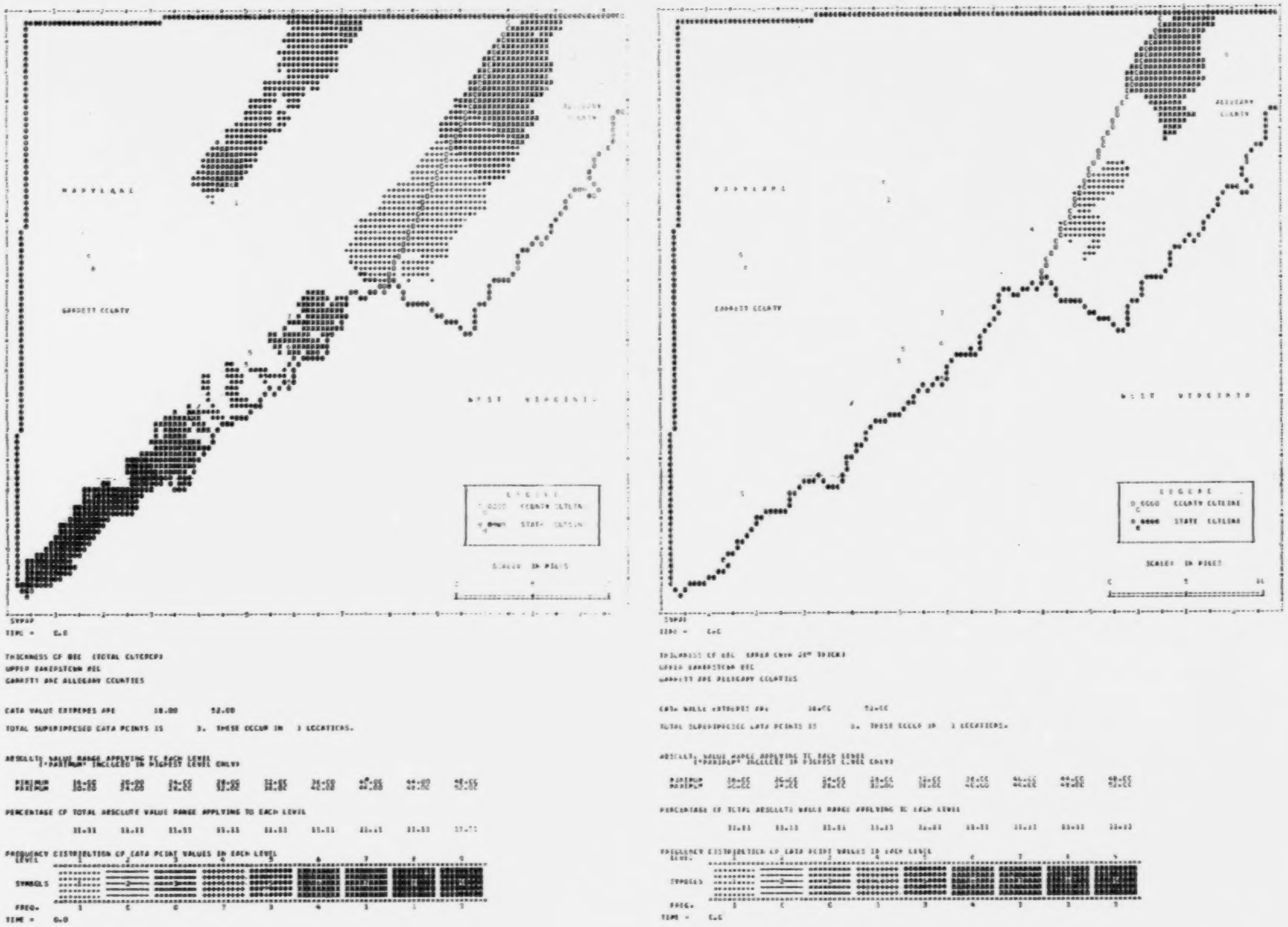


Figure F-2
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Thickness of Bed
left: total outcrop; right: area over 28" thick

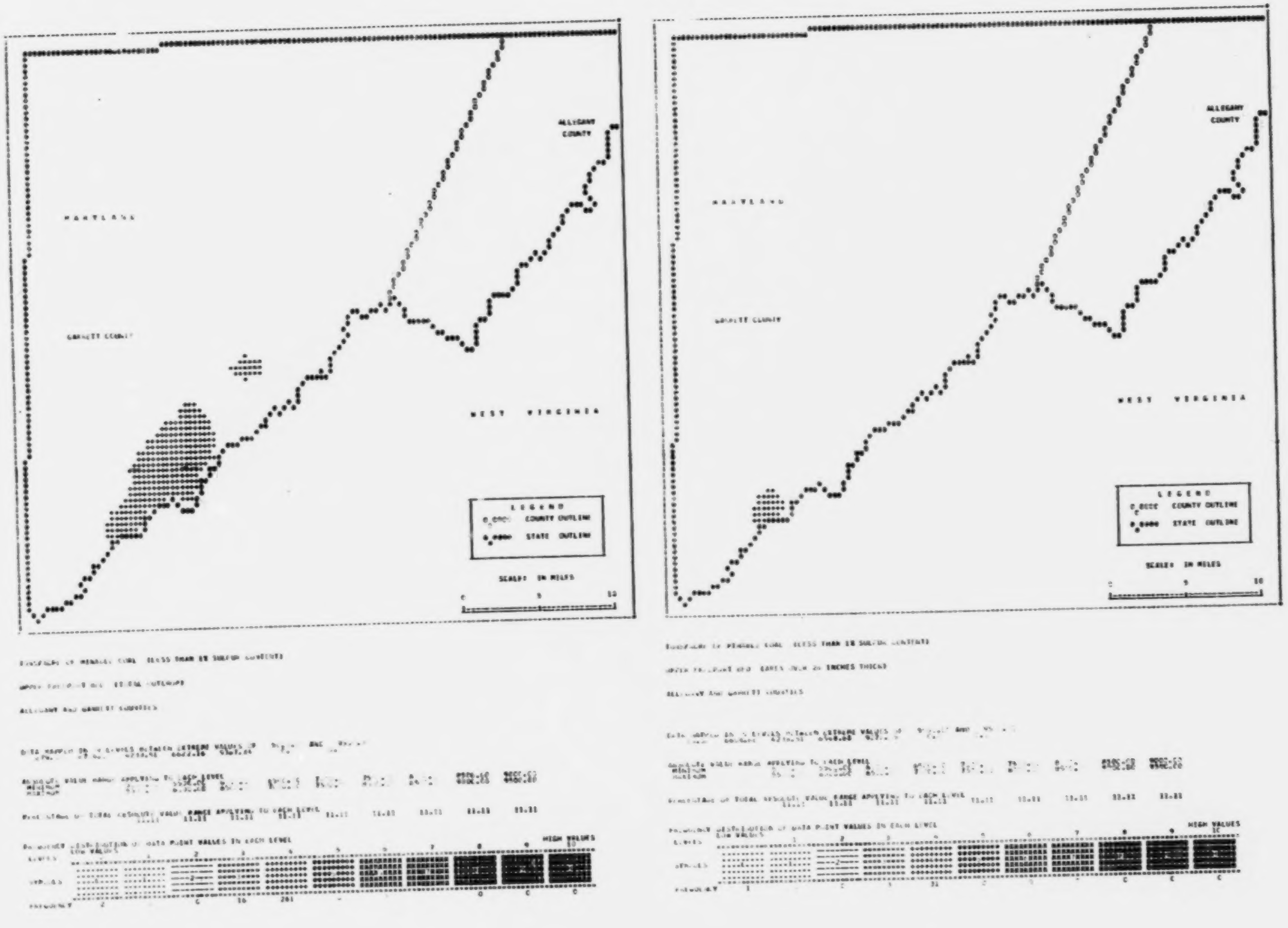


Figure F-3
Allegany and Garrett Counties
Upper Freeport Coal Bed
Quantity (in the ground) of Coal with less than 1% Sulfur
Based on Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

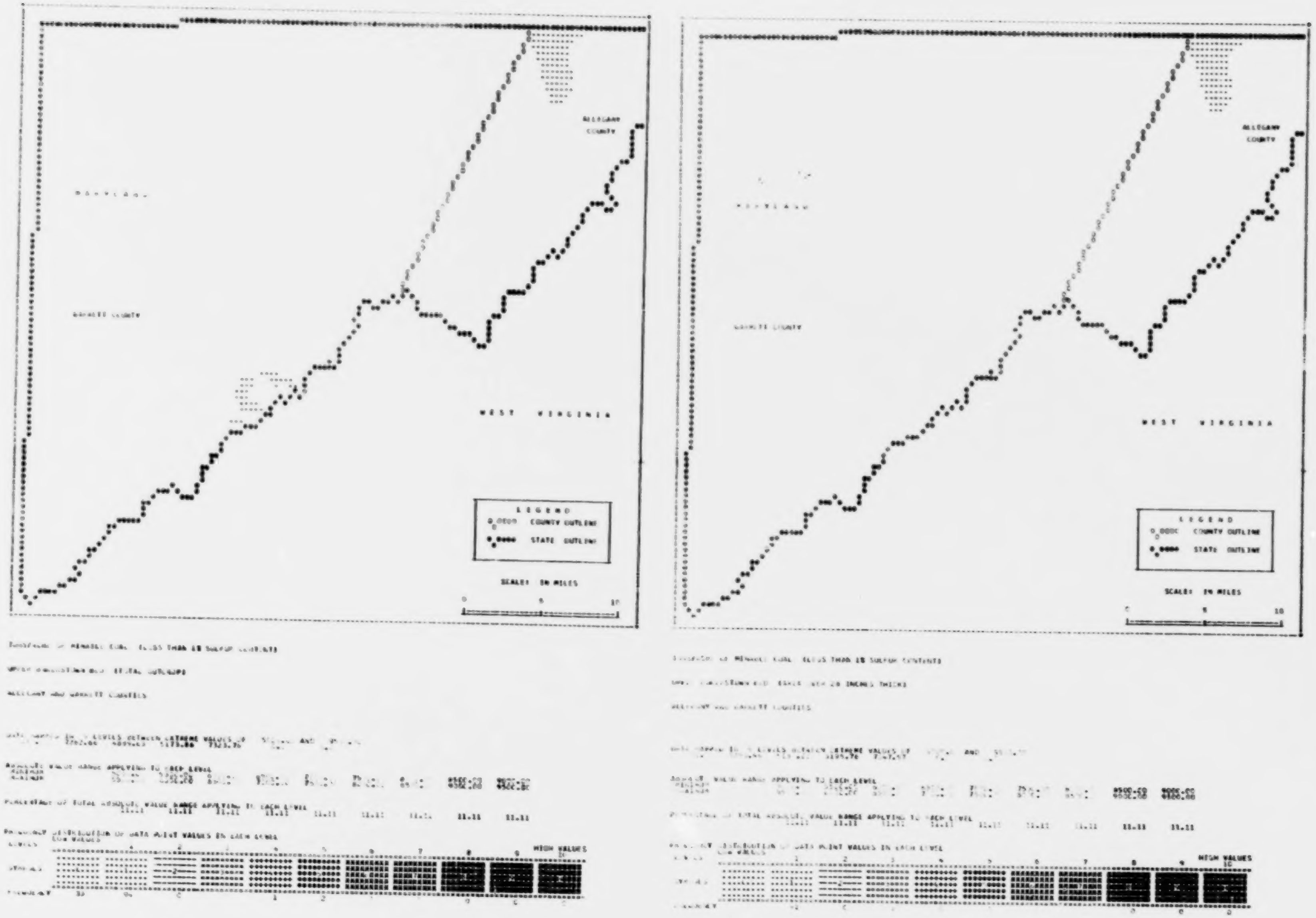


Figure F-4
Allegany and Garrett Counties
Upper Bakerstown Coal Bed
Quantity (in the ground) of Coal with less than 1% Sulfur
Based on Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick

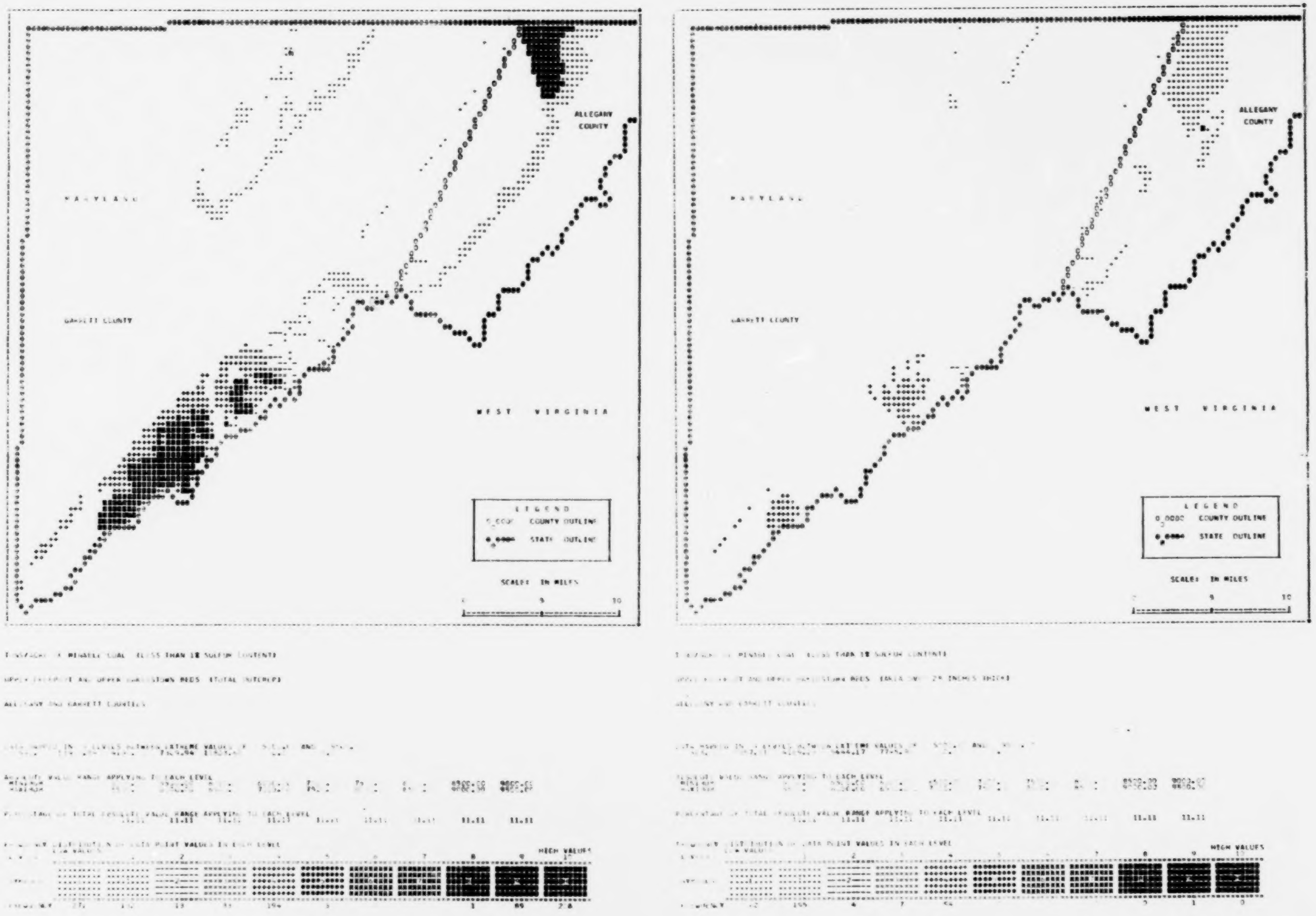
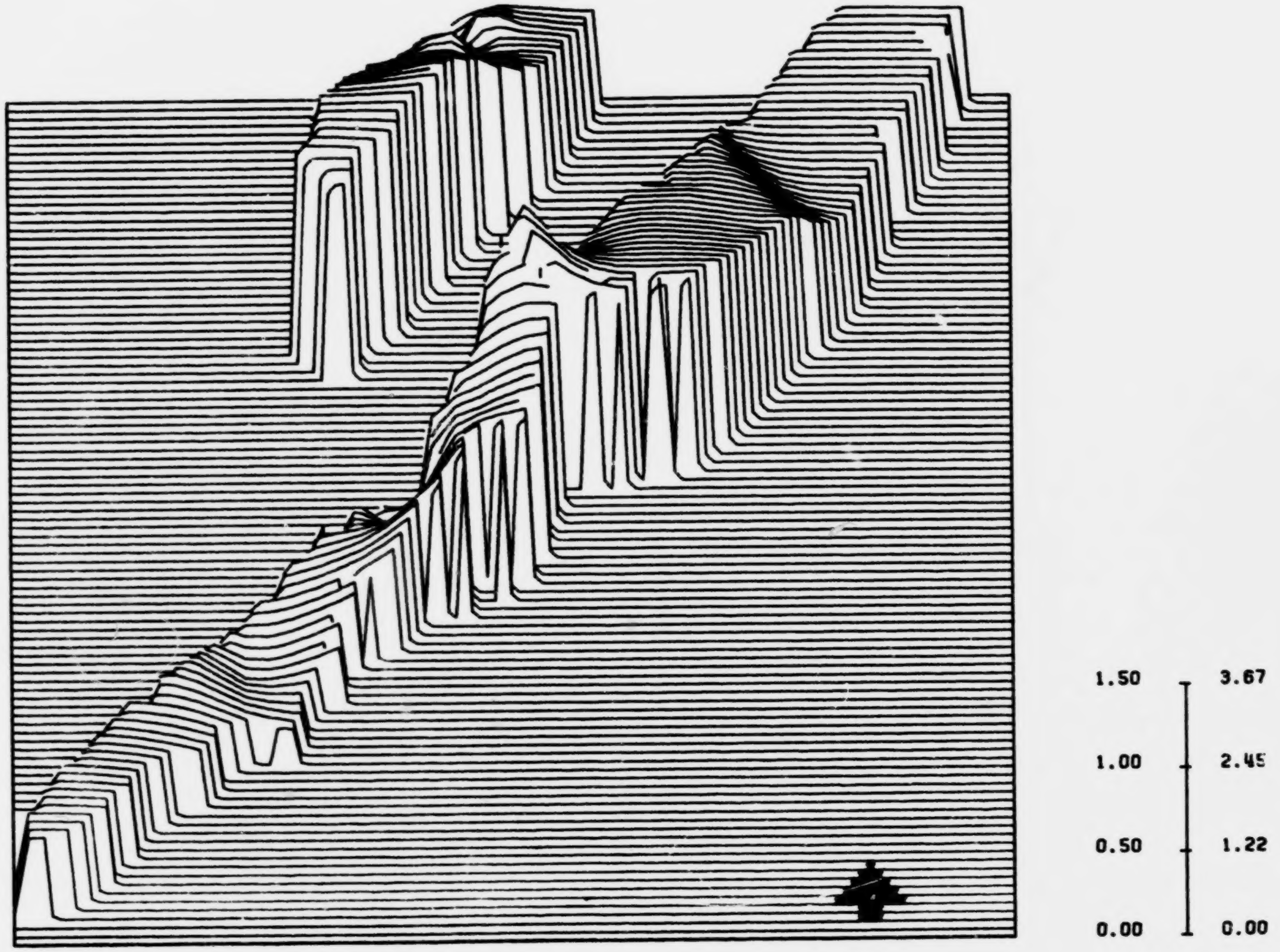


Figure F-5
Allegany and Garrett Counties
Composite of Upper Freeport and Upper Bakerstown Coal Beds
Quantity (in the ground) of Coal with less than 1% Sulfur
Based on Mode Values for Raw Samples
left: total outcrop; right: area over 28" thick



AZIMUTH = 0
WIDTH = 6.00

04/19/71

ALTITUDE = 60
HEIGHT = 3.00

Figure F-6a
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
for total outcrop; azimuth 0°

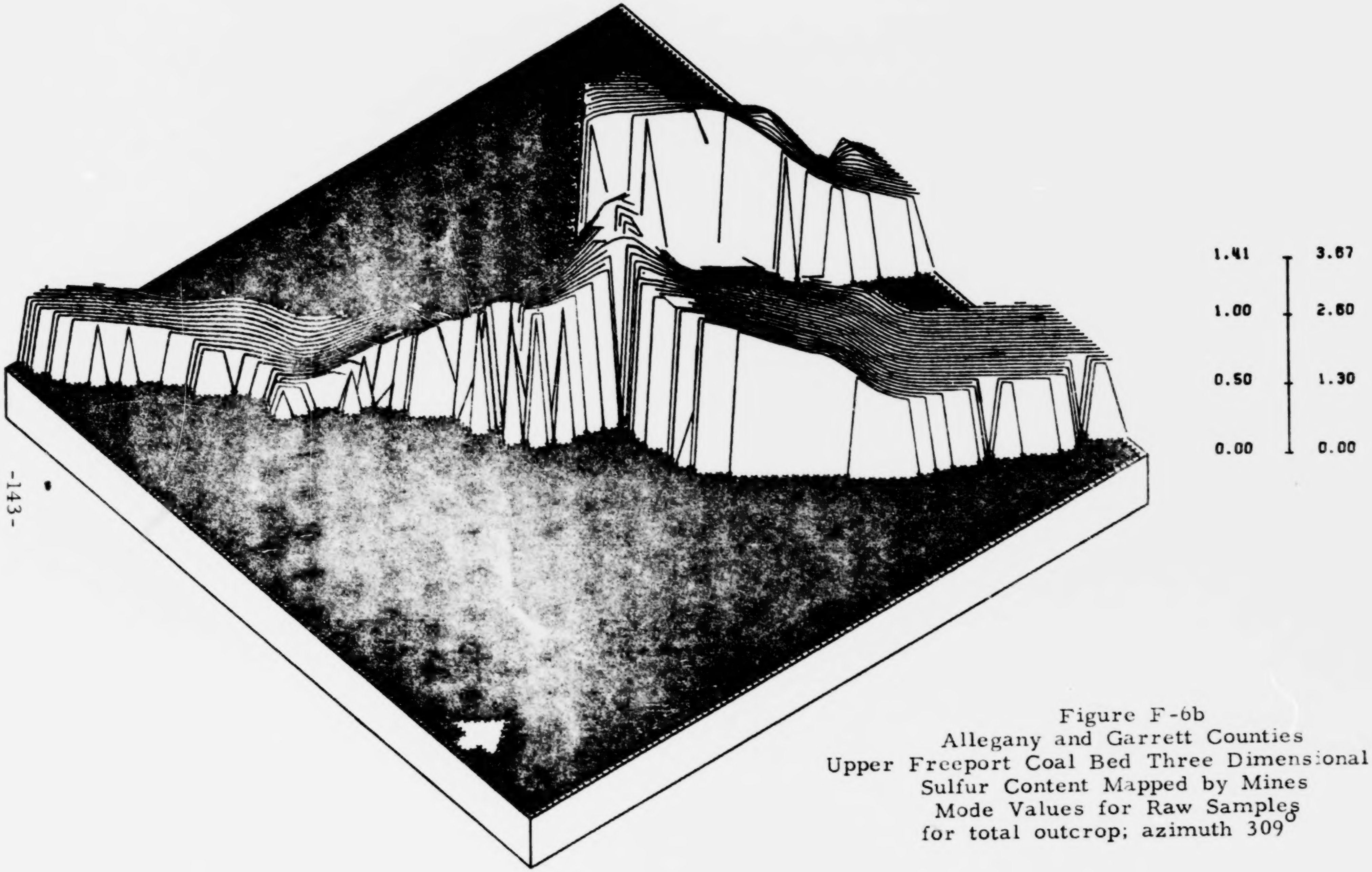


Figure F-6b
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
for total outcrop; azimuth 309°

U. FREEPORT BED (TOTAL OUTCROP), % SULFUR CONTENT (MODE), G&A CO.MARYLAND

AZIMUTH = 309 ALTITUDE = 45
WIDTH = 6.00 HEIGHT = 2.00

04/19/71

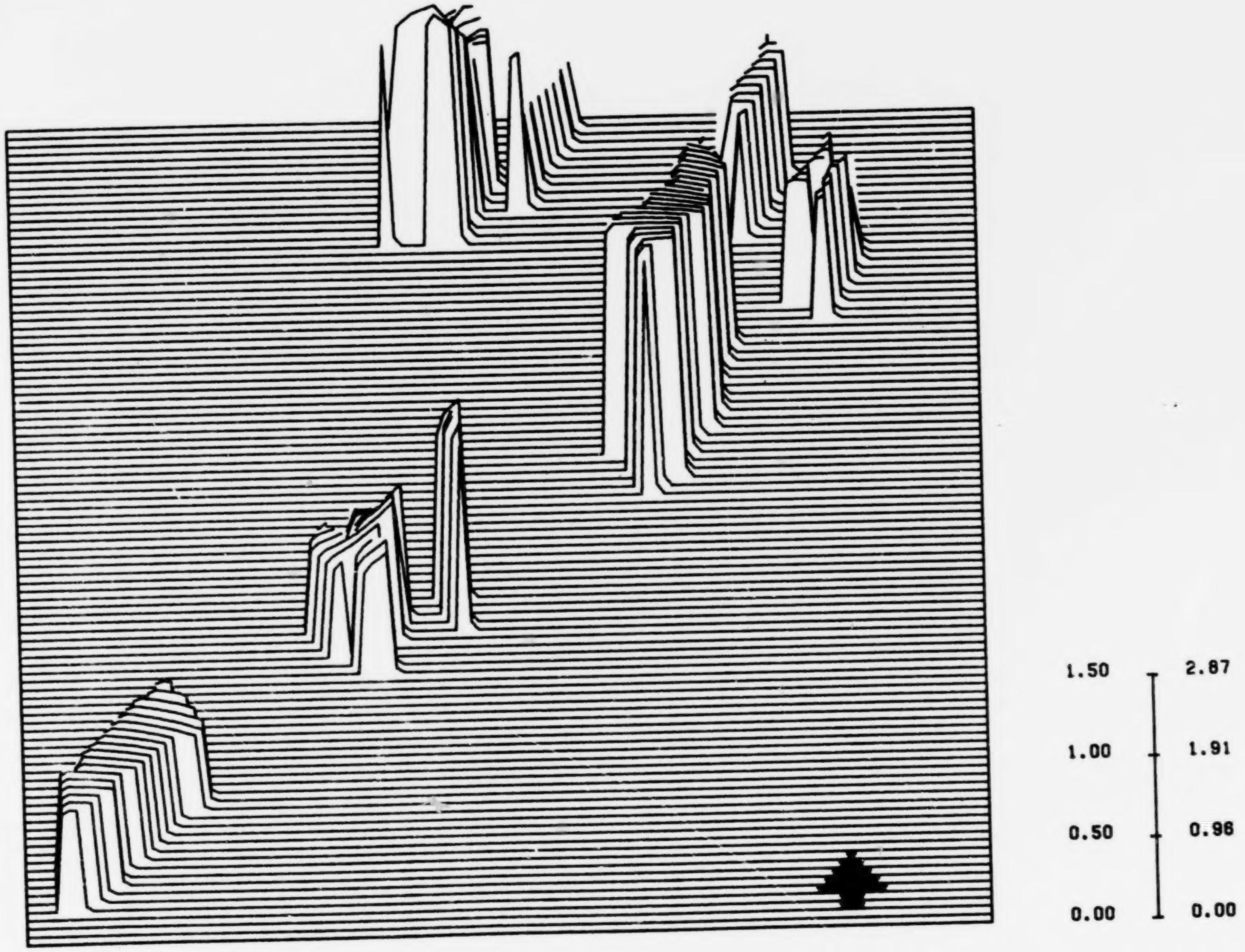


Figure F-7a
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
for area over 28"thick; azimuth 0°

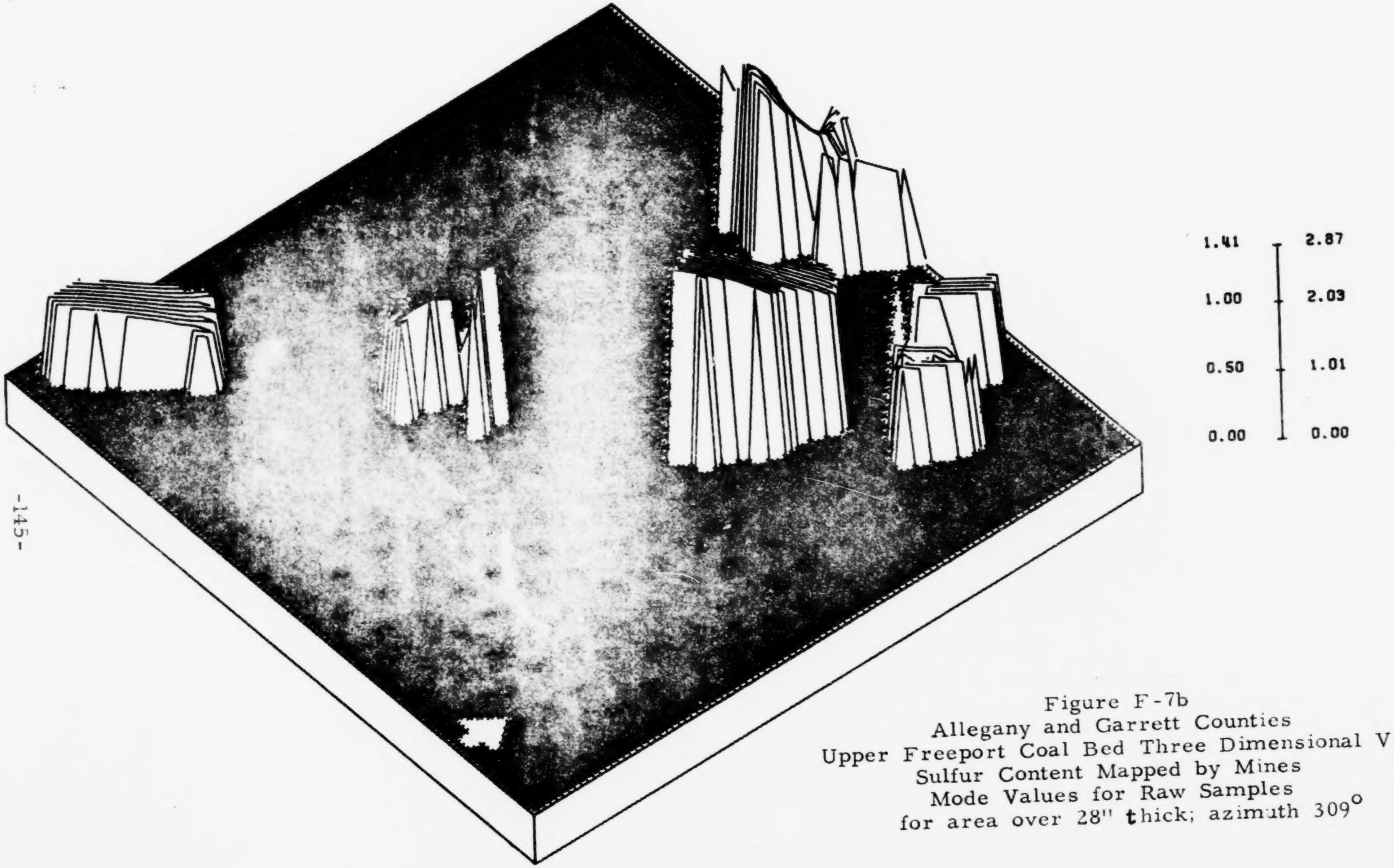


Figure F-7b
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Sulfur Content Mapped by Mines
Mode Values for Raw Samples
for area over 28" thick; azimuth 309°

U. FREEPORT BED (AREA >28"THICK).% SULFUR CONTENT (MODE).G&A CO.MARYLAND

AZIMUTH = 309 ALTITUDE = 45
WIDTH = 6.00 HEIGHT = 2.00

04/16/71

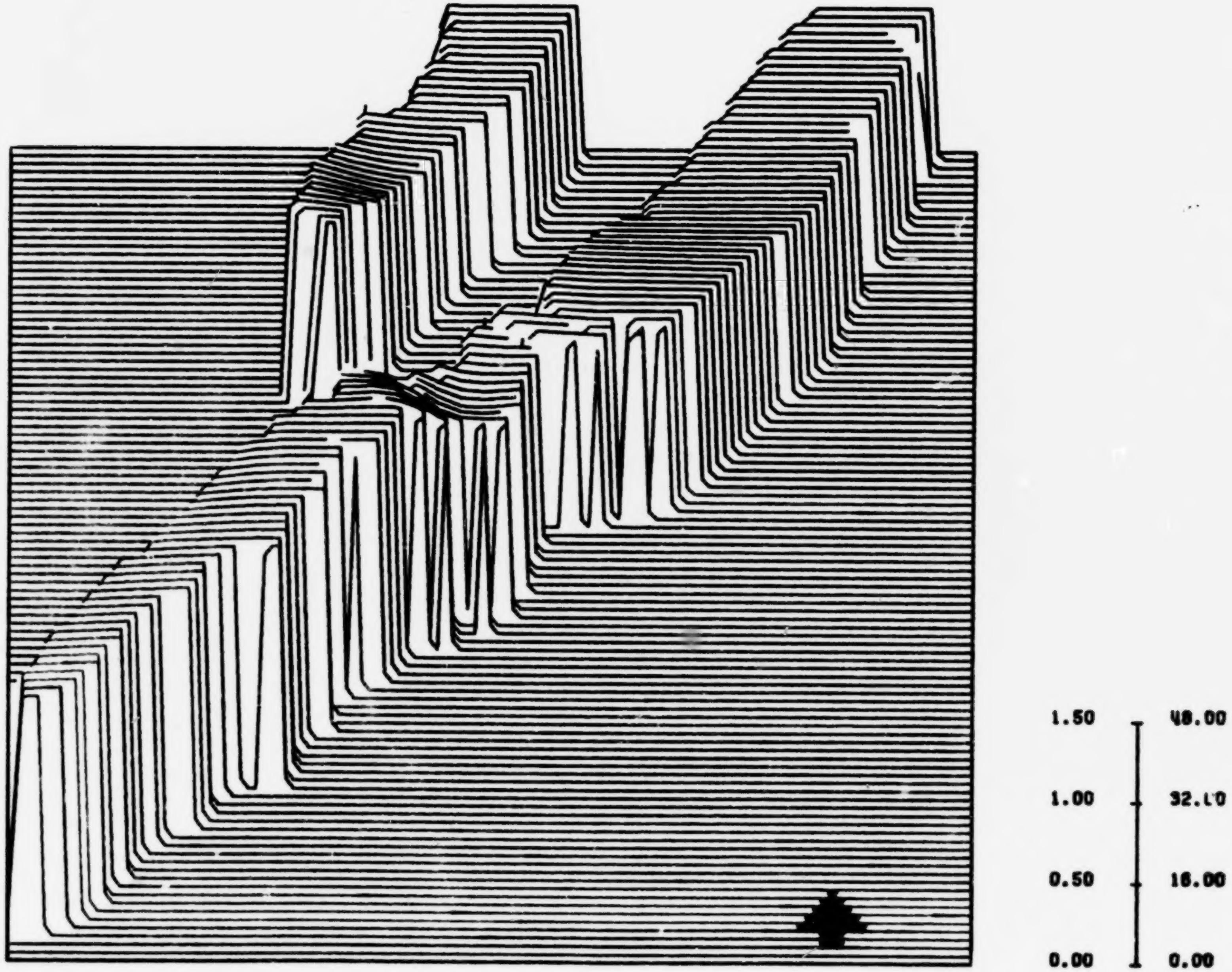


Figure F-8a
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Thickness of Bed
for total outcrop; azimuth 0°

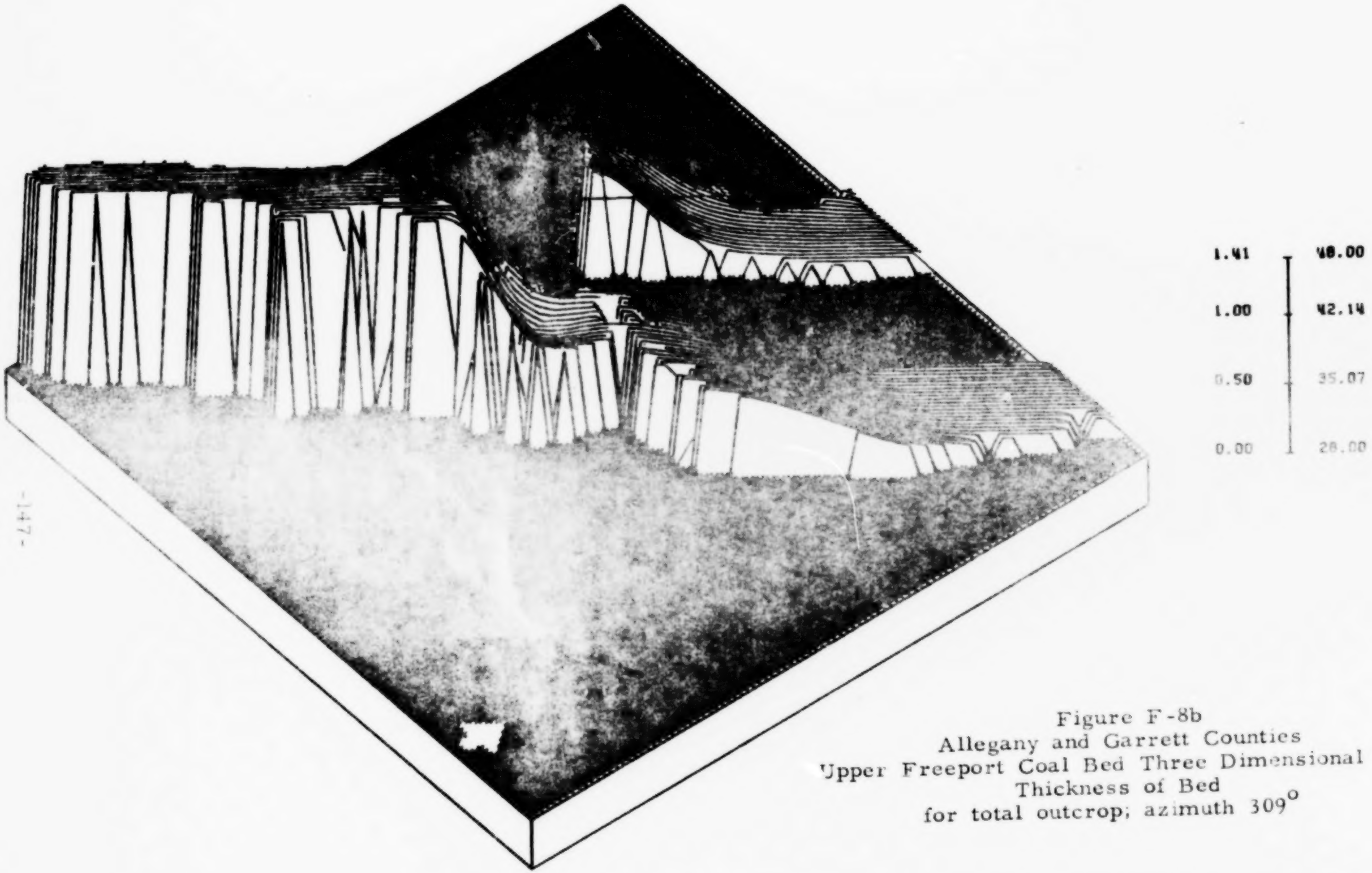


Figure F-8b
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Thickness of Bed
for total outcrop; azimuth 309°

U. FREEPORT BED, THICKNESS OF TOTAL OUTCROP, GARRETT&ALLEGANY CO. MARYLAND

AZIMUTH = 309
WIDTH = 6.00
ALTITUDE = 45
HEIGHT = 2.00

04/16/71

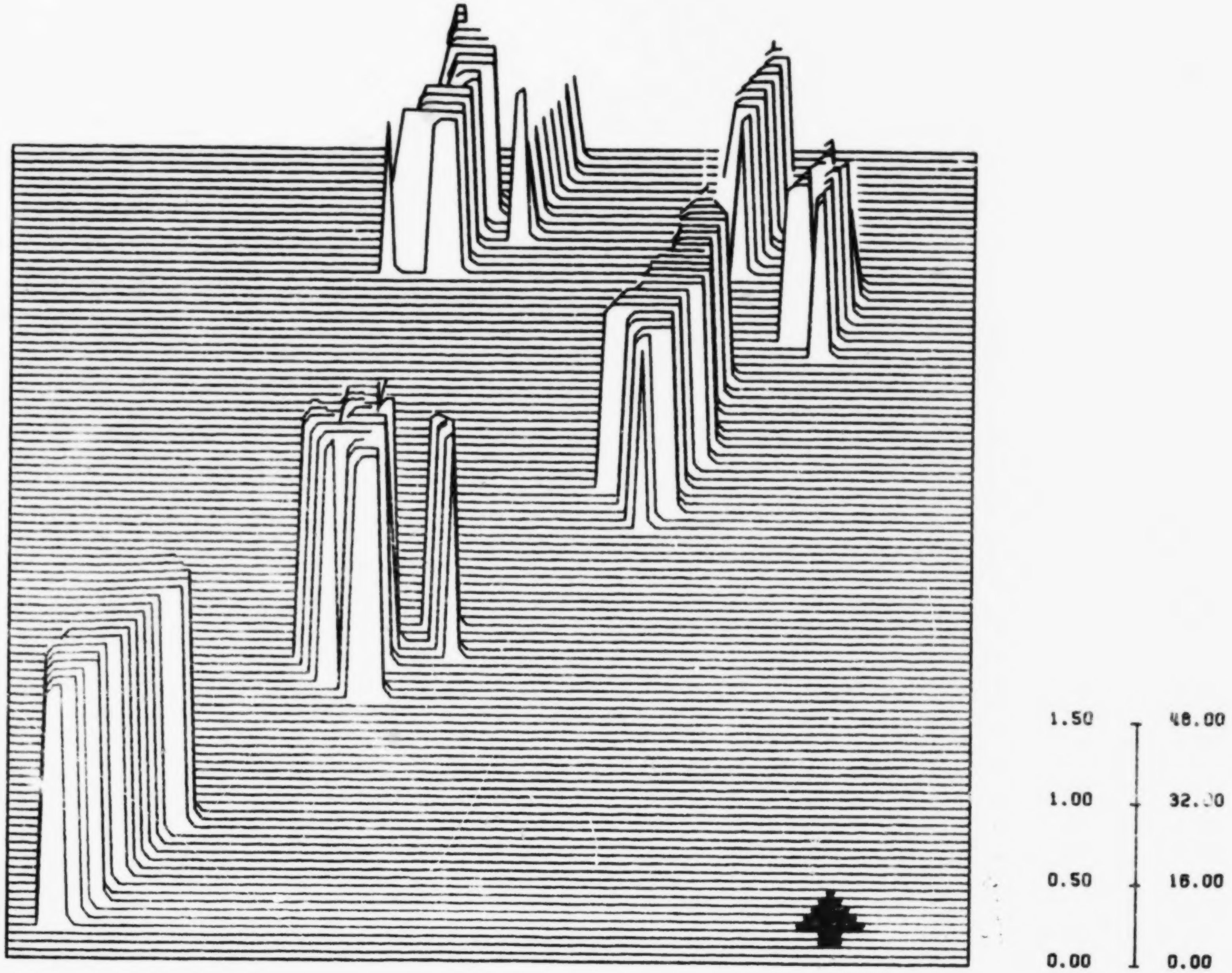


Figure F-9a
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Thickness of Bed
for area over 28" thick; azimuth 0°

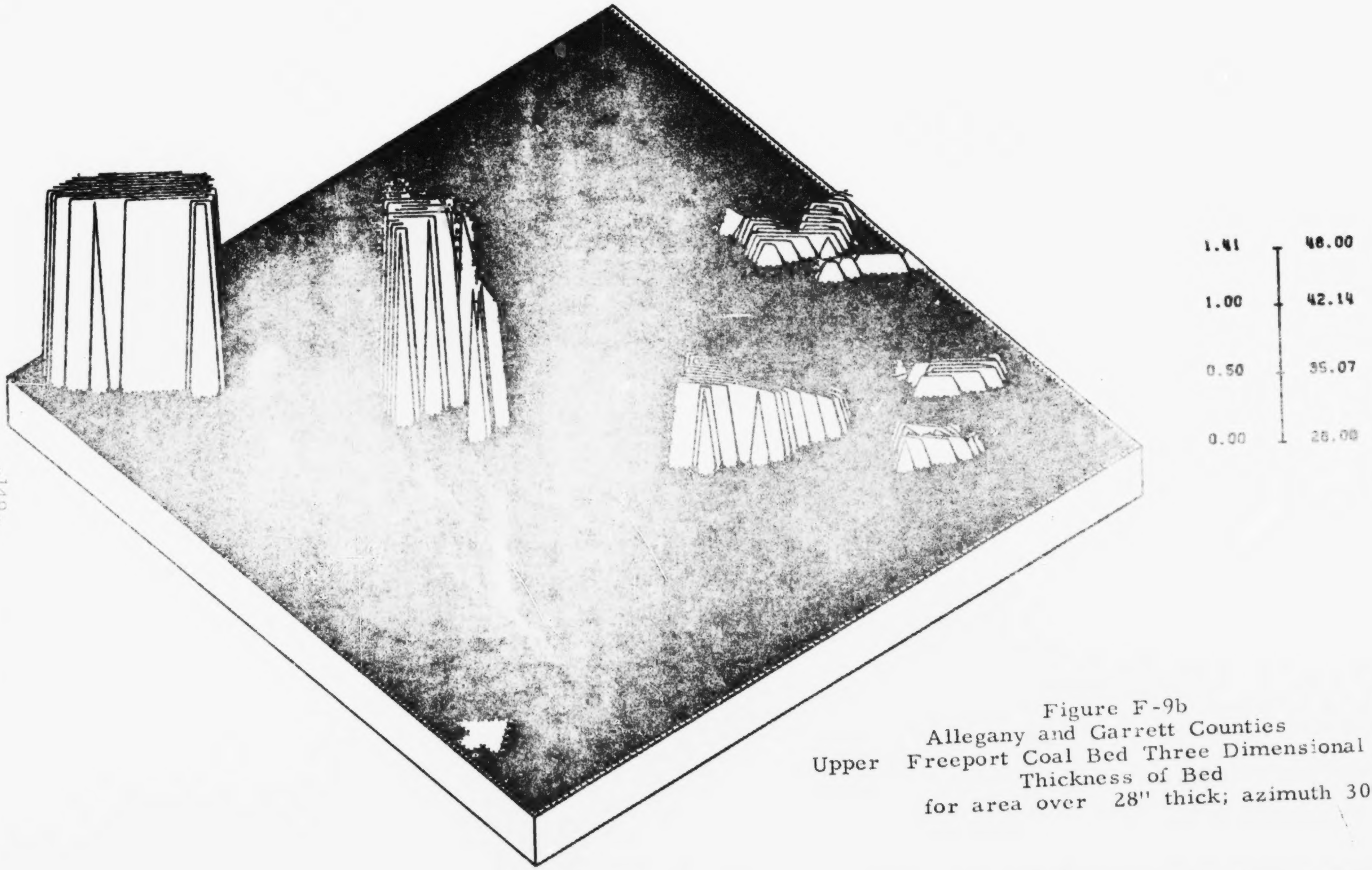


Figure F-9b
Allegany and Garrett Counties
Upper Freeport Coal Bed Three Dimensional View
Thickness of Bed
for area over 28" thick; azimuth 309°

U. FREEPORT BED, THICKNESS OF AREAS >28", GARRETT&ALLEGANY COUNTY, MARYLAND

AZIMUTH = 309 ALTITUDE = 45
WIDTH = 6.00 HEIGHT = 2.00

04/16/71

for the area over 28" thick. Figures 8a and 8b show the bed thickness for the total outcrop and Figures 9a and 9b for the area over 28" thick. These views were produced to demonstrate this particular graphical portrayal. A set of views of a surface from several different angles and altitudes can give a great deal more information about the whole surface than the arbitrary isolines of a SYMAP or GRID two-dimensional representation. With special versions of the program legends and contours between levels--such as the isoline of 1% sulfur content--can be shown on the surface.

The views chosen here are (1) "head-on", or from the south, and (2) from the southwest.

2.9. MAP SERIES G

Map series G and map series H comprise Stage Two of the mapping. This stage involves the mapping of washability data for the Upper Freeport Bed for the center portion of Allegany and Garrett Counties; this portion is shown in Figure F-1. Insufficient washability data was available for the Upper Bakerstown Bed.

Map series G is concerned only with the sulfur content resulting from the washed samples. For the Upper Freeport Bed there were useable samples at 5 locations. These had been washed to various yields through screen sizes of 3/8" mesh and 1 1/2" mesh among others. The mapping involved the sulfur content that coal could be washed to at various yields using these two screen sizes. Figure G-1 shows the base map for this series. Four of the five data points fall within the center portion to be mapped and the fifth is to the northeast; the spacing of the points is quite good, although extrapolation occurs in the southwest portion of the total outcrop. The spacing is also good for the area over 28" thick, with the exception of the southwest corner.

The total sulfur content and the sulfur content resulting if all pyritic sulfur were to be removed were mapped for purposes of comparison. Figures G-2 and G-3 show the total sulfur and total less pyritic sulfur for the 3/8" mesh screen at 60% yield for the total outcrop and the areas over 28" thick. Figures G-4 and G-5 show the same type of information for the 1 1/2" mesh screen. Not surprisingly, the greatest variability occurs in the center area where 3 of the 5 data points are located. For the total less pyritic sulfur all areas are less than 1% sulfur for either the 3/8" or 1 1/2" mesh; the northeastern and central areas are less than 1% in both cases for total sulfur.

Figures G-6 and G-7 show the differences in sulfur content between washing with a 3/8" and a 1 1/2" mesh screen for the same yield of 60%. The difference in the total sulfur between the 3/8" and 1 1/2" mesh screens is small except in the far northeastern corner of the study area. In all cases the sulfur content is greater with the 1 1/2" mesh screen. The patterns reflect the location and number of data points and are particularly evident in the very sharp contour intervals. For the total less the pyritic sulfur, the difference is larger than for the total sulfur data alone.

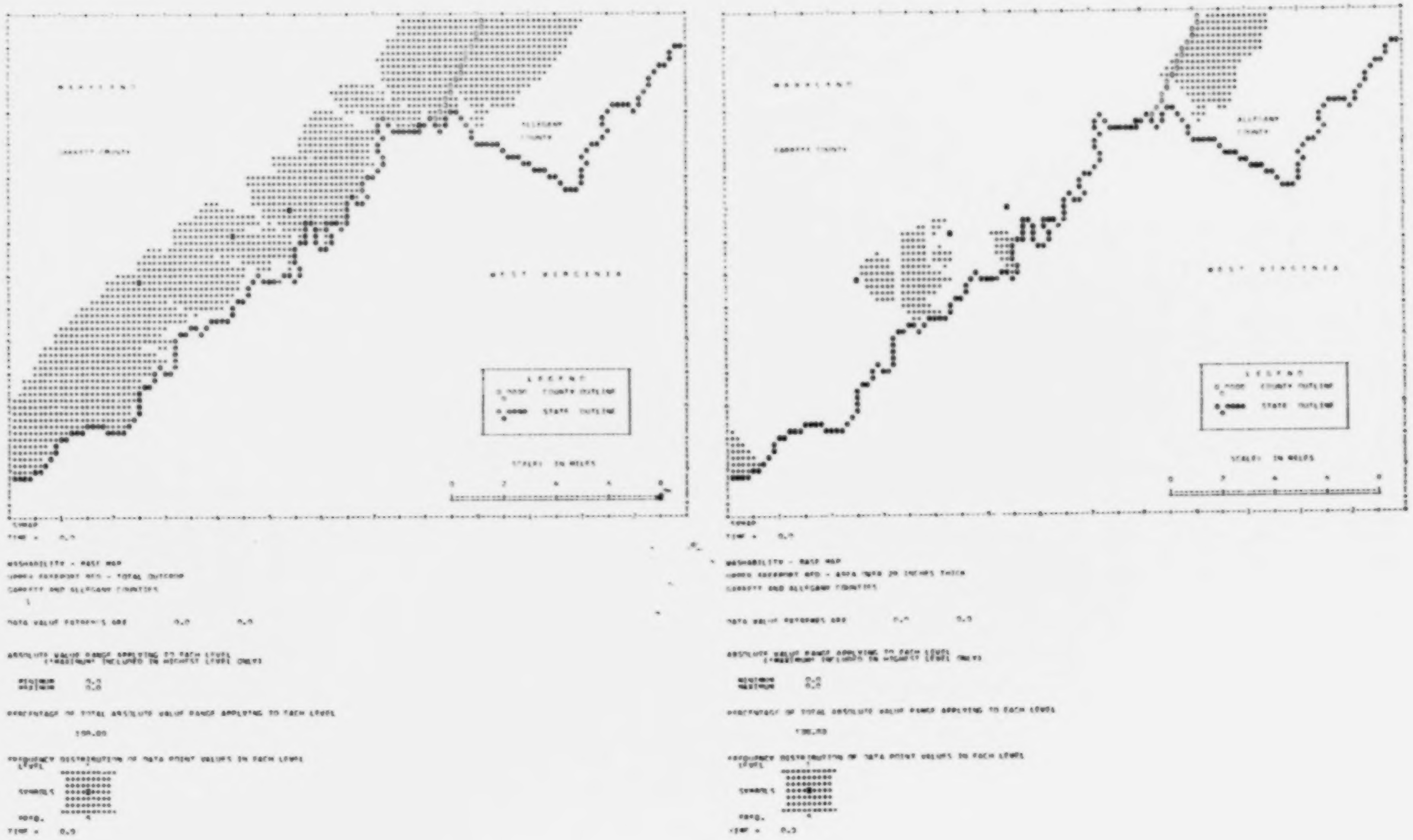


Figure G-1
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
Base Map of Samples
Left: total outcrop; right: area over 28" thick

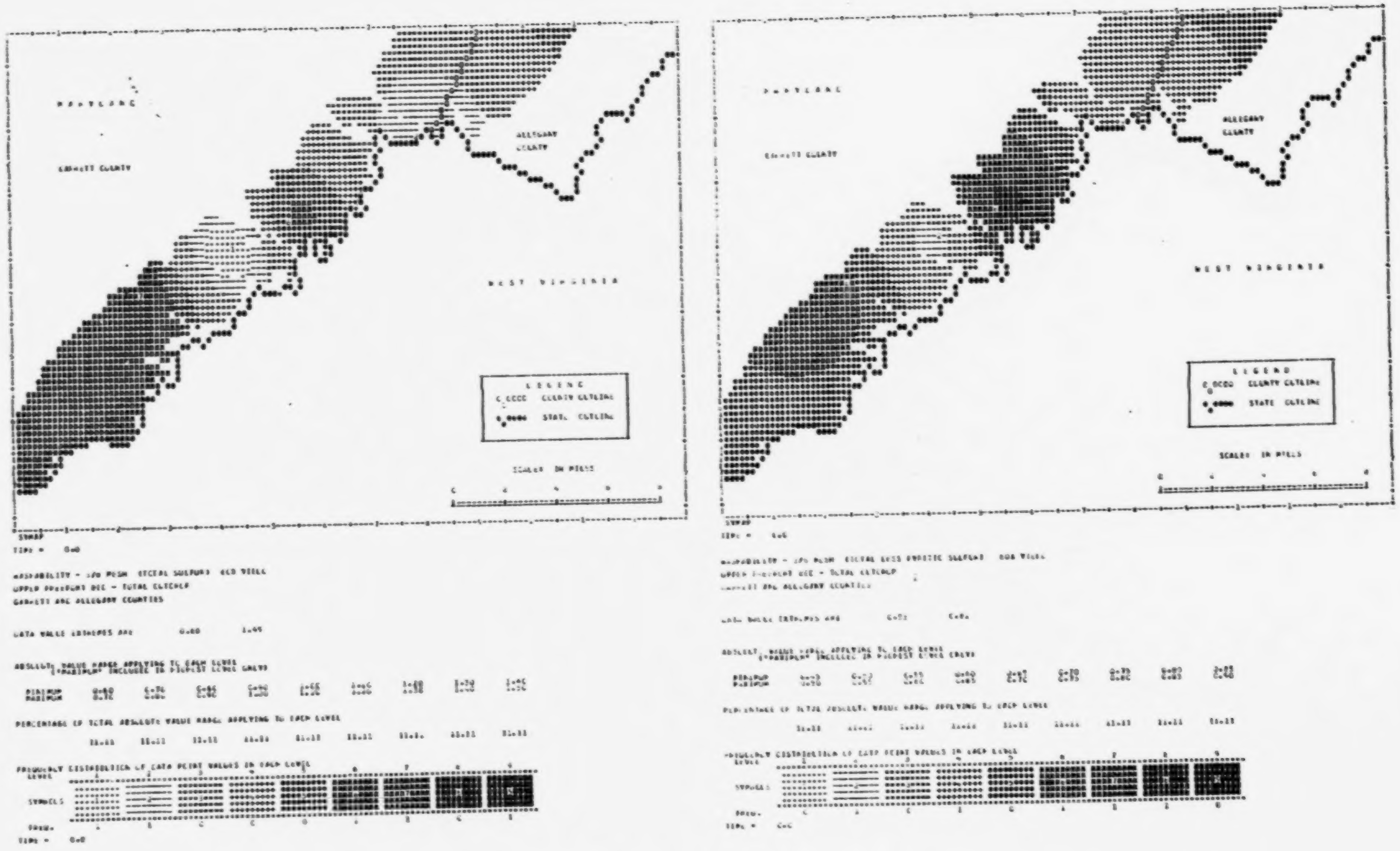


Figure G-2
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
3/8" mesh; for total outcrop
left: total sulfur; right: total less pyritic sulfur

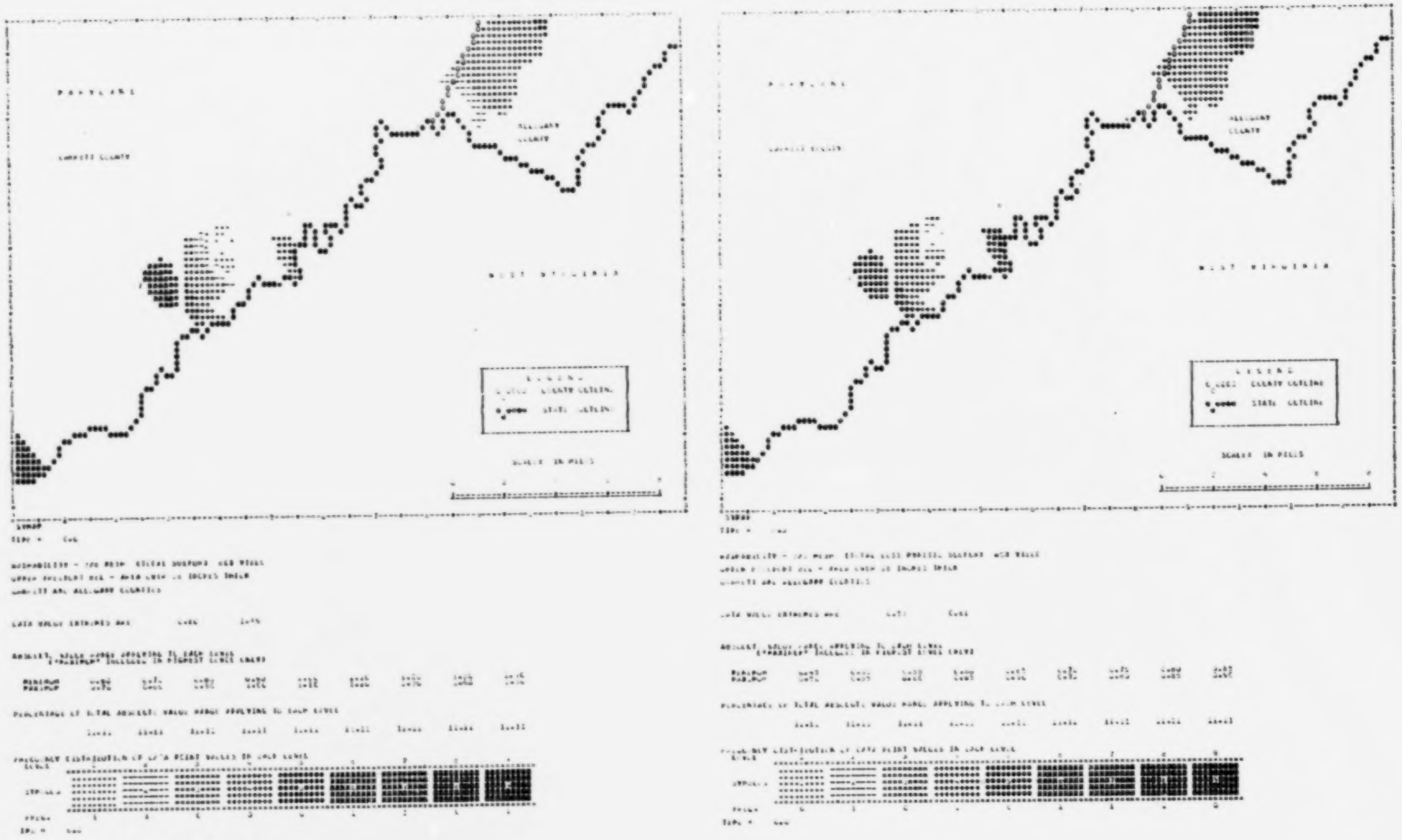


Figure G-3
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

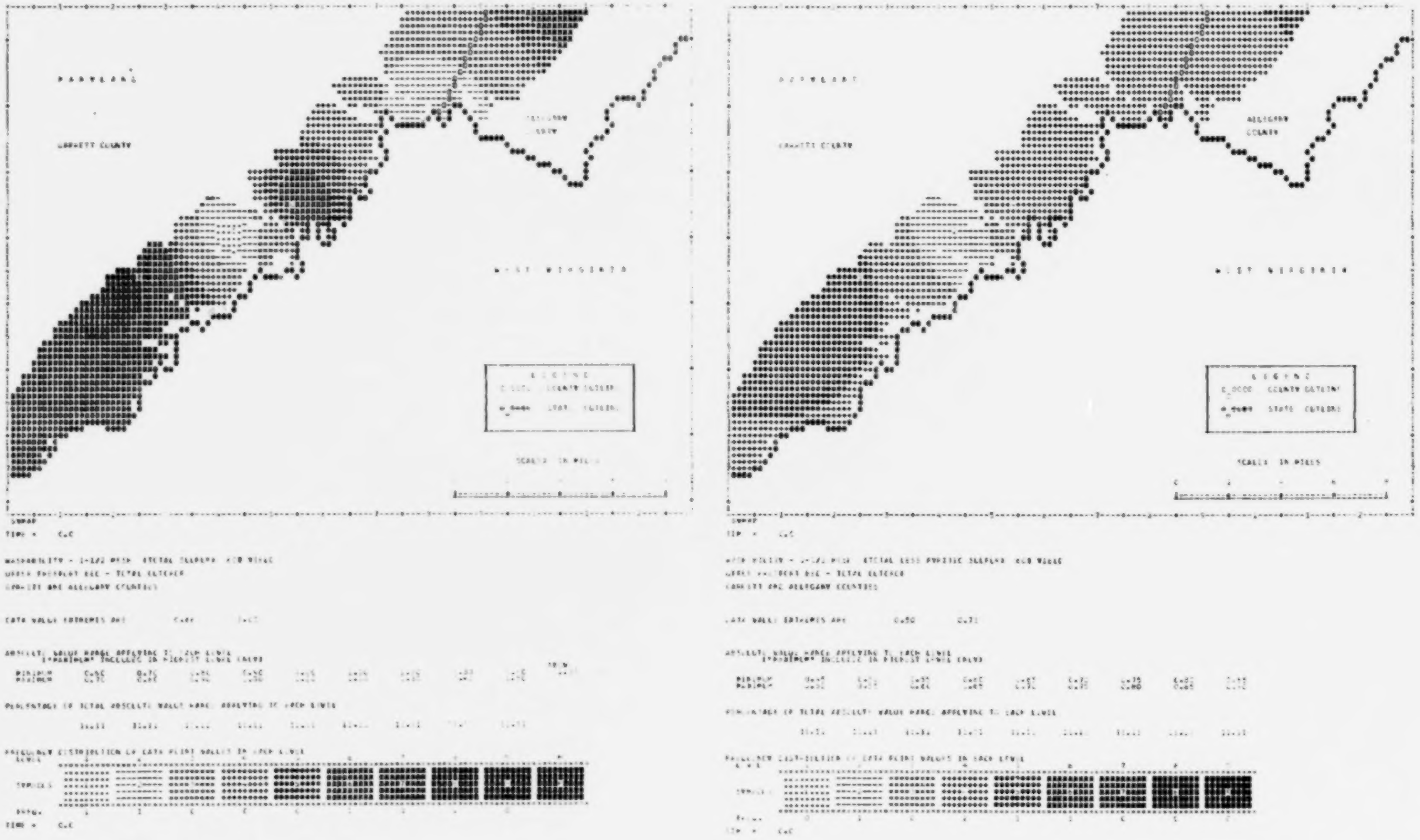


Figure G-4
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
1 1/2" mesh; for total outcrop
left: total sulfur; right: total less pyritic sulfur

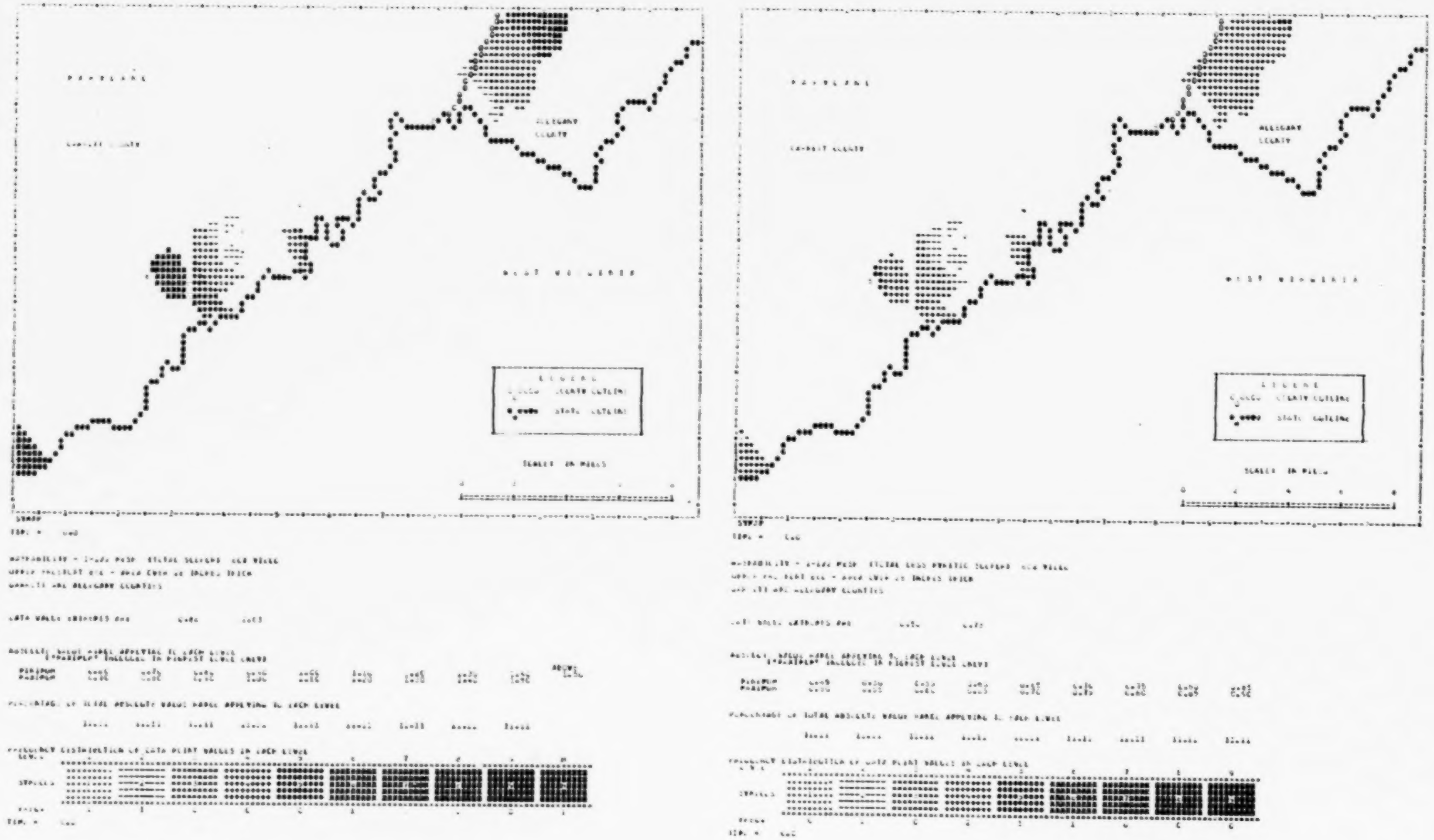


Figure G-5
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
1 1/2" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

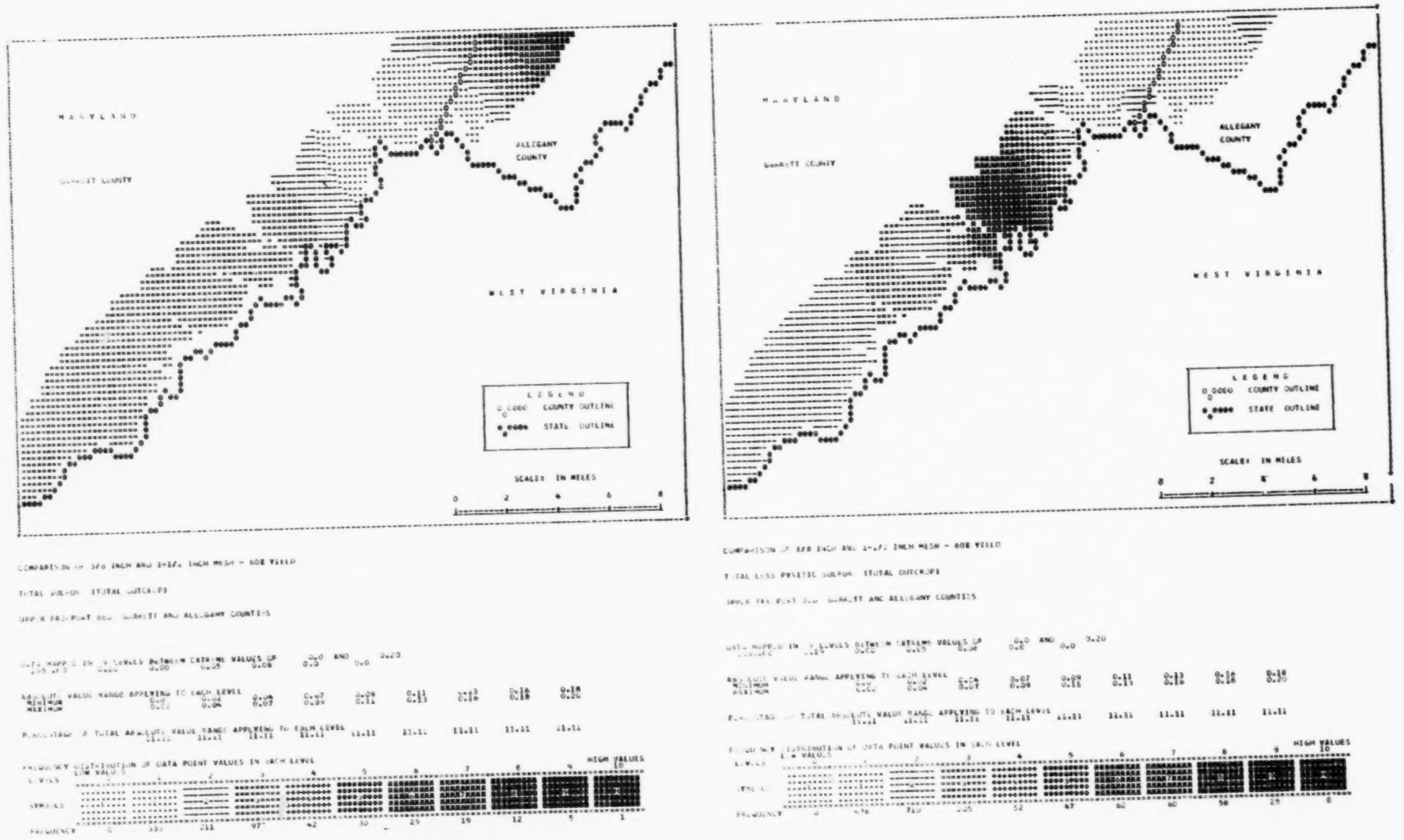


Figure G-6
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
Comparison of 3/8" and 1 1/2" mesh; for total outcrop
left: total sulfur; right: total less pyritic sulfur

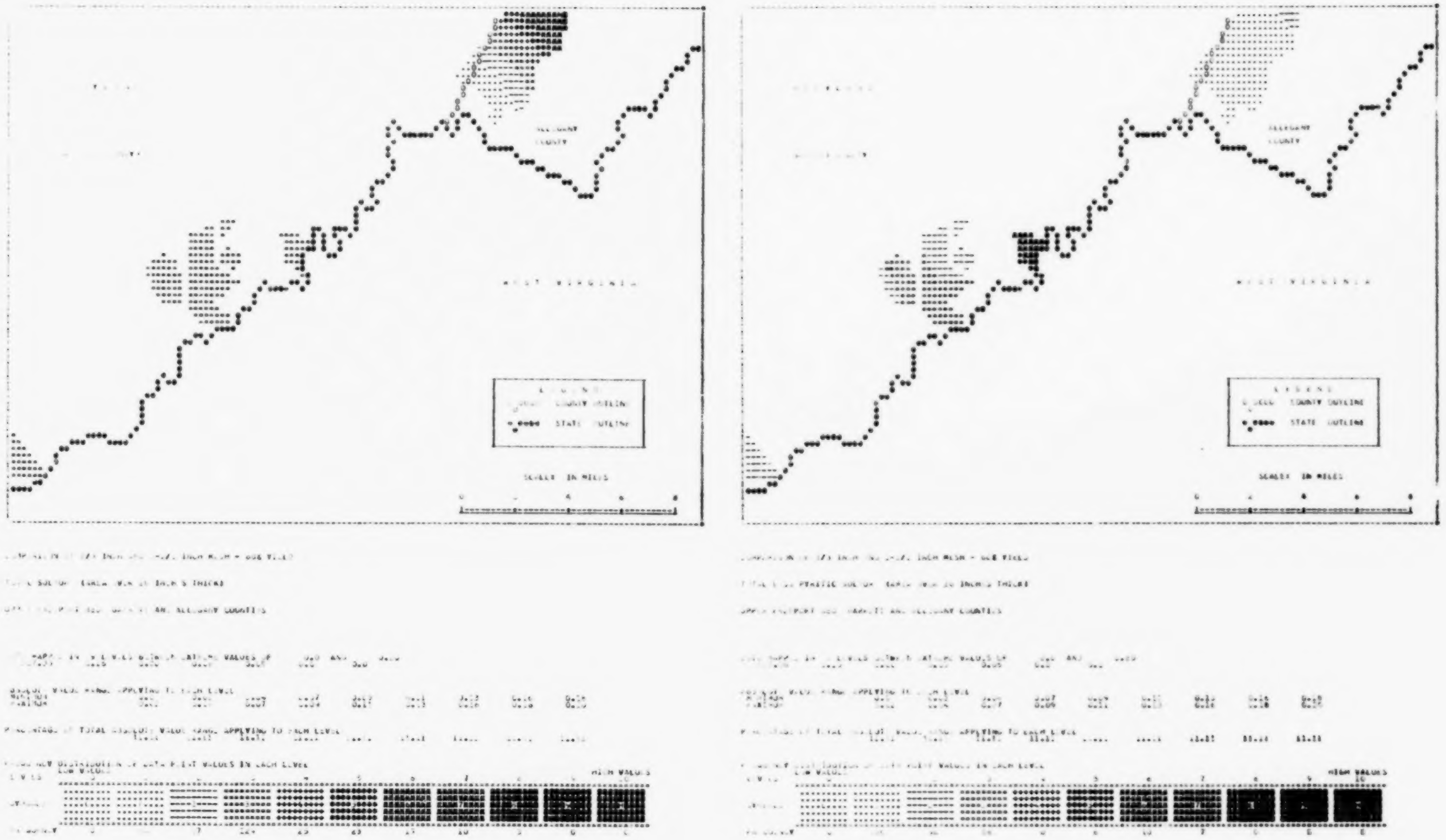


Figure G-7
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 60% yield
Comparison of 3/8" and 1 1/2" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

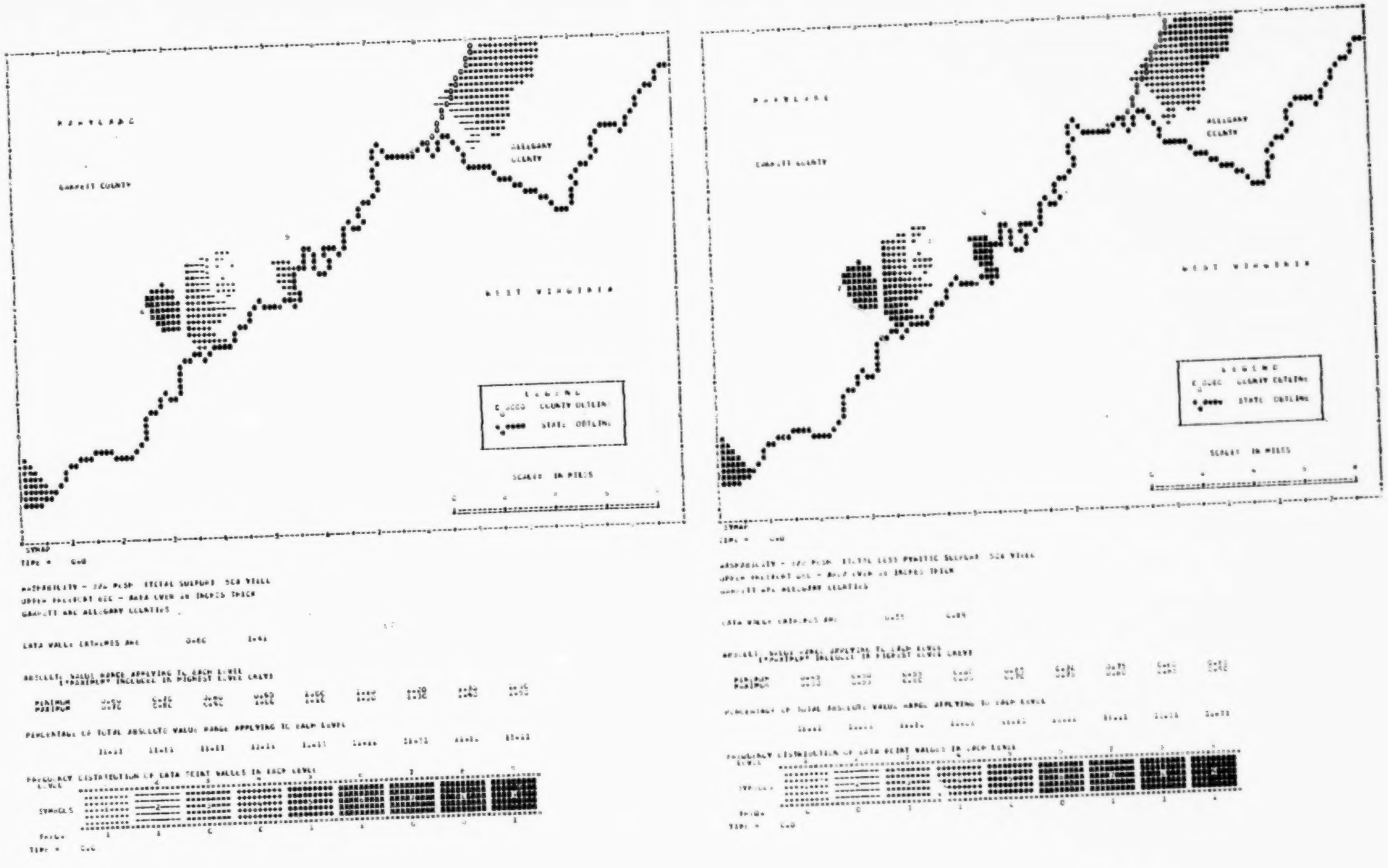


Figure G-8
Center Portion of Allegany and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 50% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

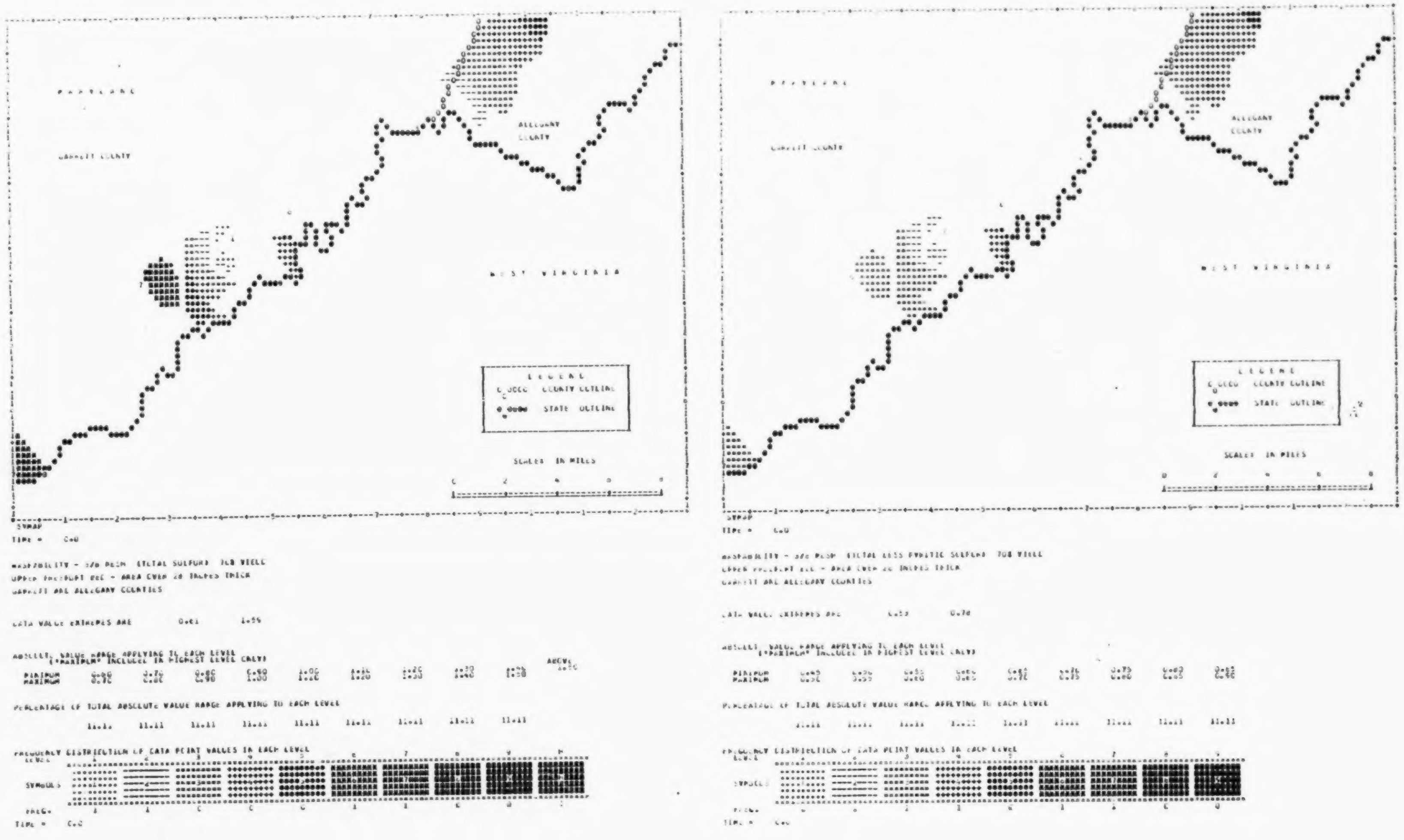


Figure G-9
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 70% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

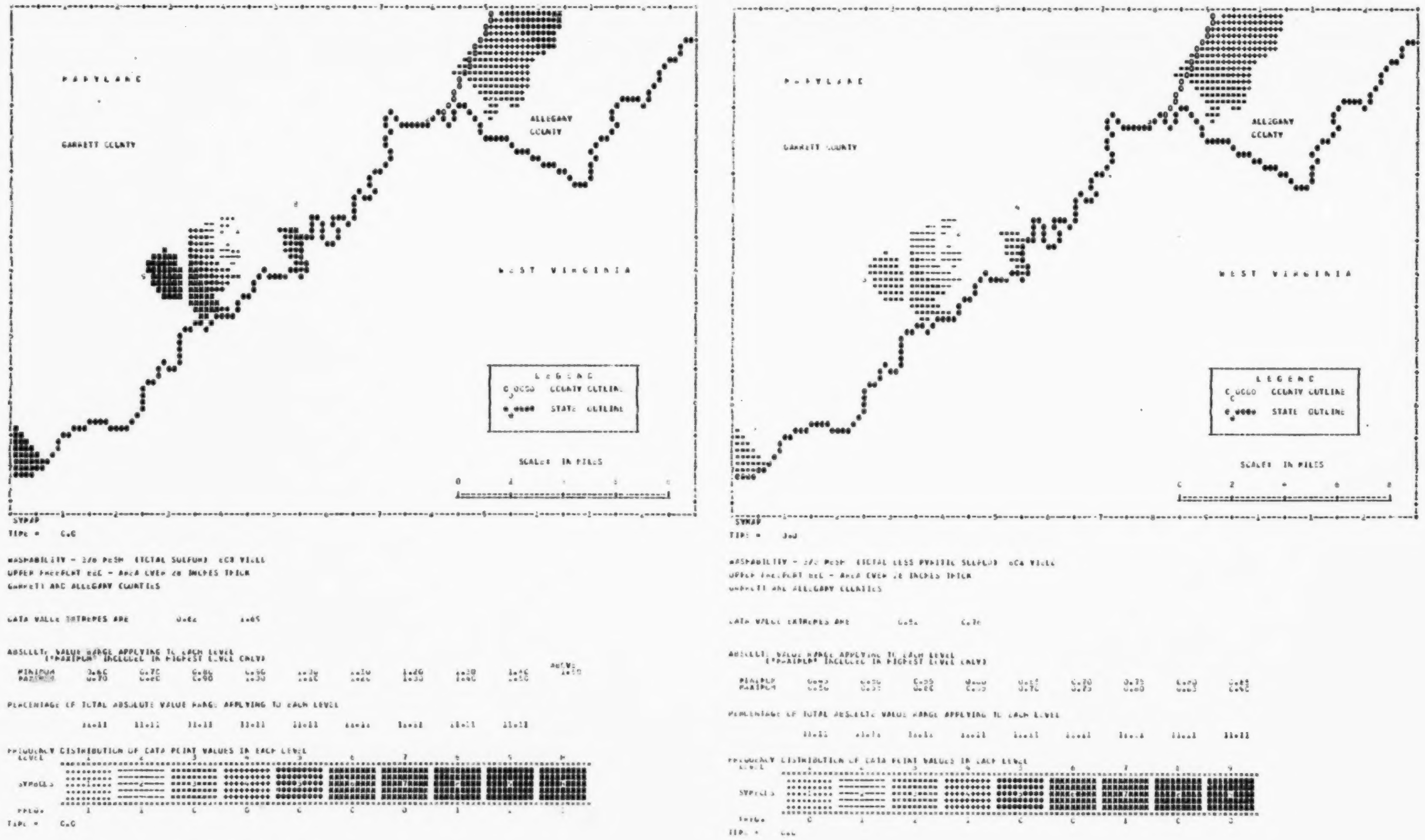


Figure G-10
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Sulfur Content of Washed Coal
At 80% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

This area of greatest difference is in the center and is undoubtedly related to the location of the washability data points. We cannot make any conclusions as to the reduction in sulfur content due to using a 3/8" versus a 1 1/2" mesh screen since the data are too scanty for this case; the graphic technique should, however, prove useful.

The final set of maps in Series G (Figures G-8 thru G-10) show the same type of sulfur information as Figure G-3 for the area over 28" thick but with different yields using a 3/8" mesh screen. For these particular washability analyses mapped for the Upper Freeport Bed, yields of 50%, 60%, 70%, or 80% do not significantly affect the sulfur content. This would be intuitively apparent from the sample plot of sulfur content versus yield shown in Figure 2. For the total less the pyritic sulfur all values are less than 1.0% sulfur regardless of yield; non are less than 0.5% sulfur. For total sulfur in all cases 2 of the 5 values were less than 1.0% and none were less than 0.5%.

2.10. MAP SERIES H

The final map series shows the quantity of coal that would be expected to be available assuming the washability mapped in Series G and the bed thickness mapped in Series F. All of the maps in this series were produced with the GRID program. As previously discussed, the reliability of the thickness data is very suspect and the spatial interpretation of the washability data limited due to the number of data points; consequently, it is not possible to draw any conclusions as to the actual quantity of coal that might be available for this particular study area. In fact, it would be grossly misleading to attempt to draw any such conclusions. All of our mapping and analysis efforts do, however, reinforce the initial hypothesis that the techniques are a powerful tool for this application as long as we can provide sufficient data.

Figure H-1 shows the quantity of coal washed to less than 1% sulfur (at 50% recovery, assuming deep mining so as to give conservative estimates) in tons per acre for a 60% yield with a 3/8" mesh screen. This data was mapped for the total outcrop for both total sulfur and total less pyritic sulfur. The map of total less pyritic sulfur is directly proportional to the thickness map shown in Figure F-1 since: (1) all of the outcrop is less than 1% sulfur for total less pyritic, and, (2) quantity is directly proportional to thickness for those areas where sulfur content is less than 1%.

Figures H-2 thru H-5 show the same information as Figure H-1 for the areas over 28" thick for 60%, 50%, 70%, and 80% yield, respectively. These four pairs of maps differ slightly in terms of (1) the quantity at any character location mapped in direct proportion to the percent yield, and (2) the cells mapped, depending upon the small variations in sulfur content found in Figures G-3, G-8, G-9, and G-10 respectively. If sufficient reliable data had been available these subtle differences and distinctions might have proven significant and could easily have been quantified as in Figure H-7.

The final maps in this series attempted to show the differences in quantity of coal obtained by washing to a specified yield of 60%. First of all the quantity that could be recovered with 100% yield was determined and mapped in Figure H-6. Figure H-6 is merely a map of the central portion of Figure F-3 at a larger scale; the quantities at each location are multiplied by 50% to estimate the quantity of the reserves that would be recovered. It is interesting to note that the scale change from Figure F-3 to Figure H-6 reveals a small pocket of coal not shown in Figure F-3 for the areas over 28" thick. Figure H-7 shows the additional quantities of coal that would be recoverable by washing to a 60% yield.

When we examine the difference maps for the 100% yield surface (the quantities determined from the raw sulfur data points) and the 60% yield surface (determined from the washability data) we can only make a comparison for a small center portion of the study area. This is the only area where the spread of data points from the two sets of data is in any way compatible. For all other portions of these maps there are data points for only one of the two sets of data. In addition the thickness data are best for this portion of the study area.

Mapping quantity of coal in tons per acre by grid cell may not be the best procedure: quantity is a variable that is better aggregated for areas than displayed spatially as a surface. On the other hand sulfur content and bed thickness are variables that lend themselves well to spatial presentation as surfaces. To show useful information for both sulfur content and quantity at the same time the following procedure might be appropriate:

1) map sulfur content as done in this study.

2) map bed thickness as done in this study.

3) critical isolines such as 0.5% or 1.0% could be determined as in this study and a map made showing these for each of the yields.

4) for each area between isolines, such as the area greater than 0.5% but less than 1.0%, the quantity of coal could be calculated based on the varying bed thickness for those areas.

5) these quantities could be printed out below the map or as legends on the map in the appropriate shaded level.

6) the reader can then chose the sulfur content of interest to him and visually see the extent of the area involved and the quantities of coal in all those areas of lesser sulfur content.

7) comparisons can be made between various yields, and screen sizes, with quantities calculated and displayed in a similar manner.

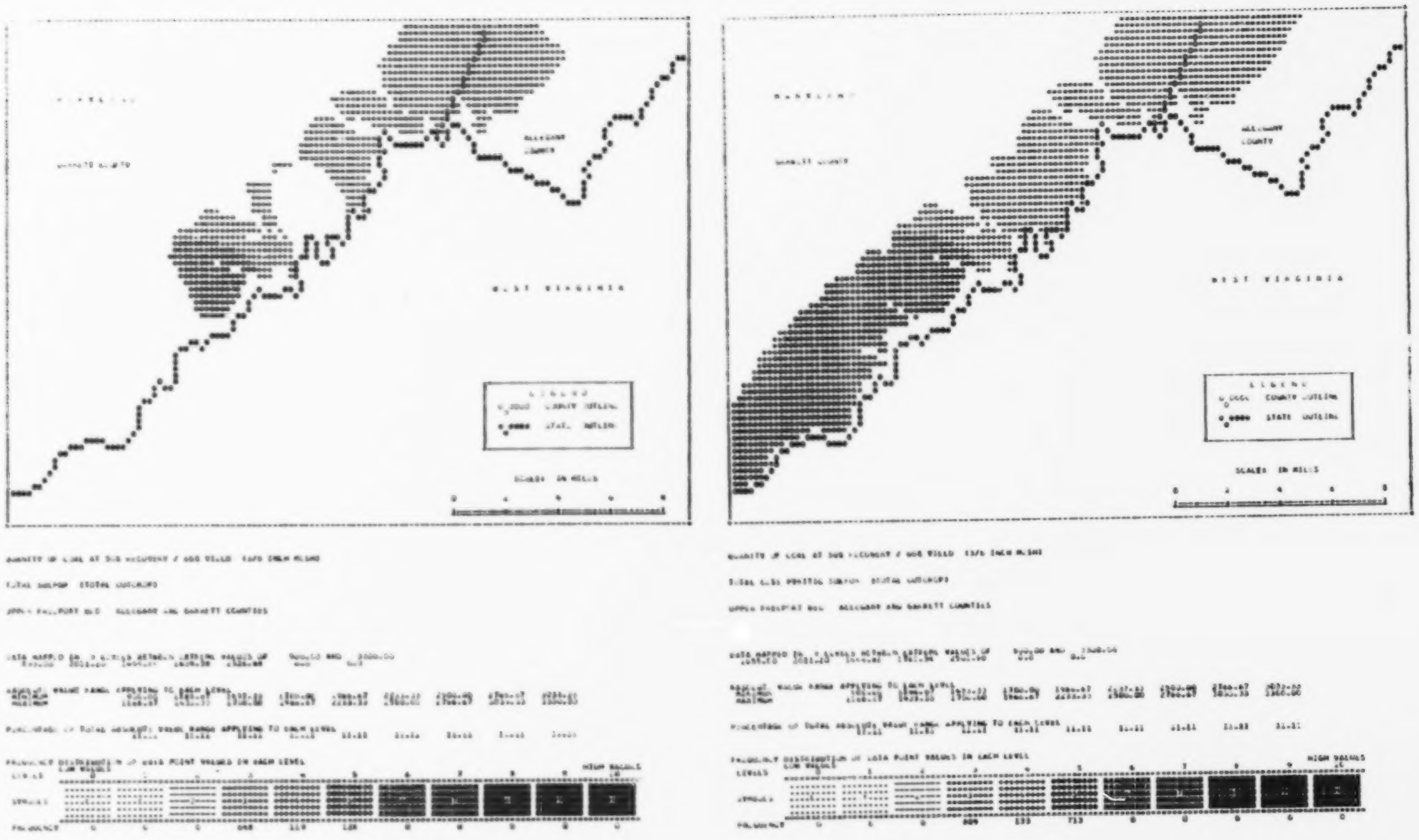


Figure H-1
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 60% yield
3/8'' mesh; for total outcrop
left: total sulfur; right: total less pyritic sulfur

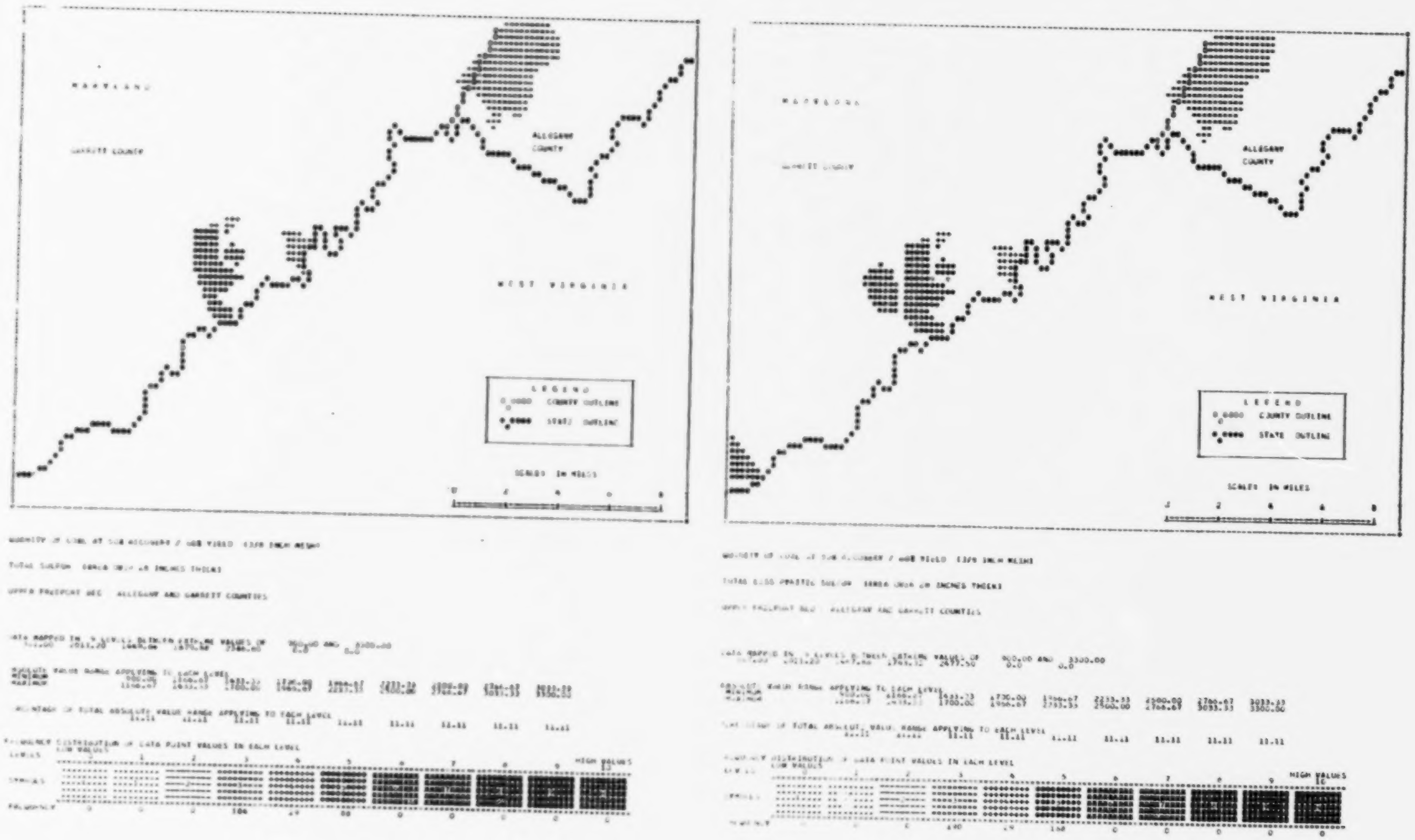


Figure H-2
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 60% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyrific sulfur

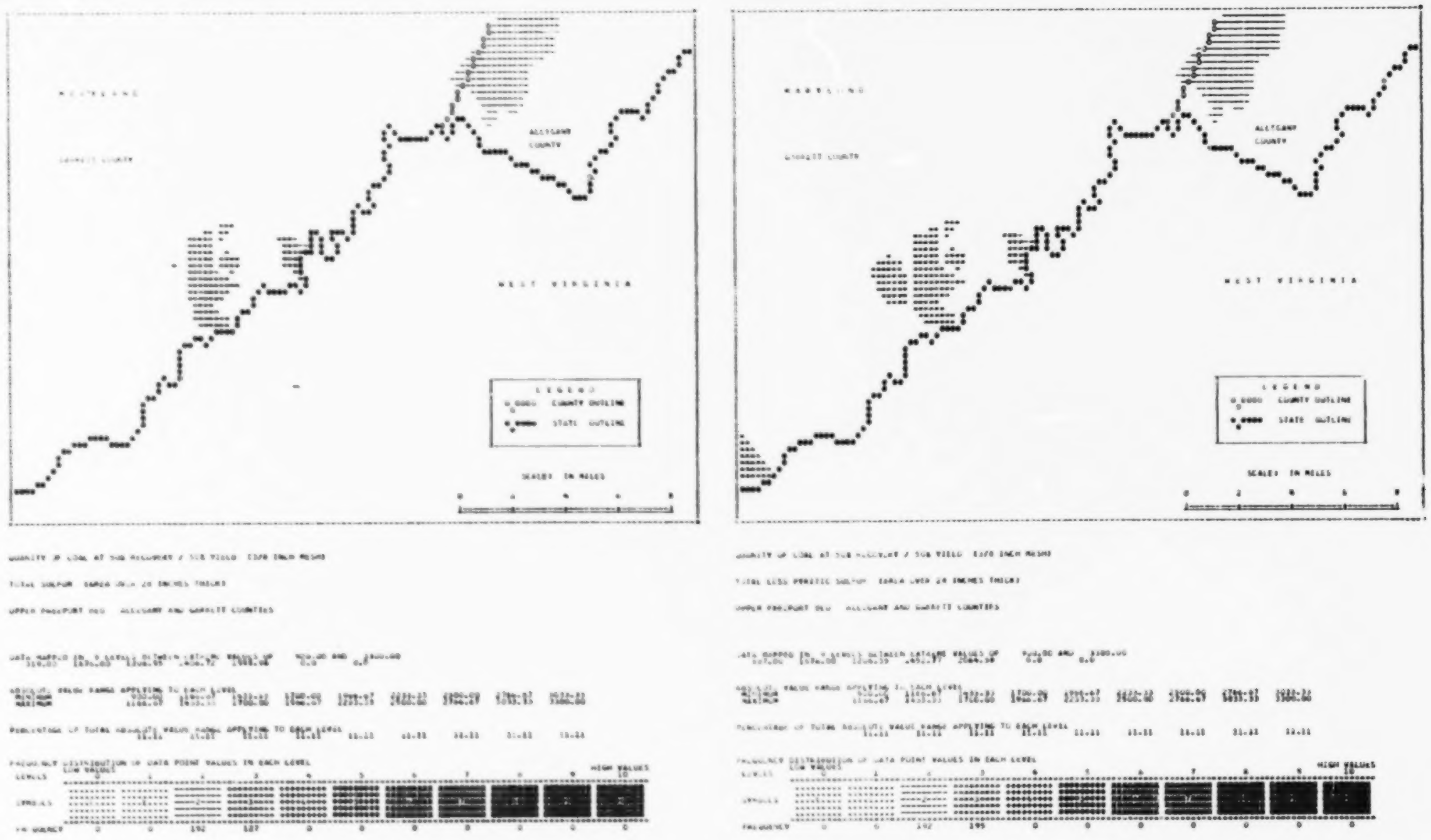


Figure H-3
Center Portion of Allagheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 50% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyritic sulfur

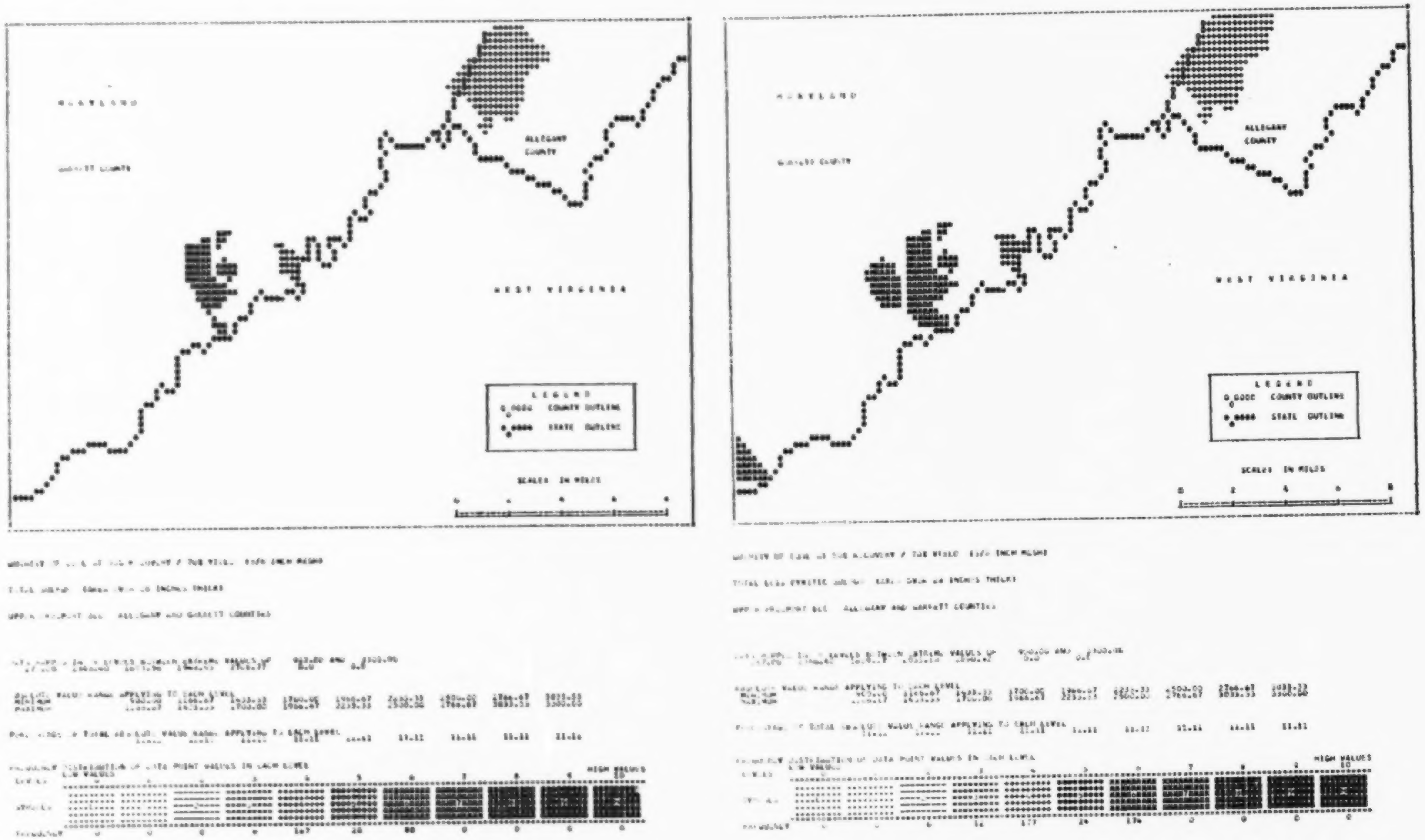


Figure H-4
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 70% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyrific sulfur

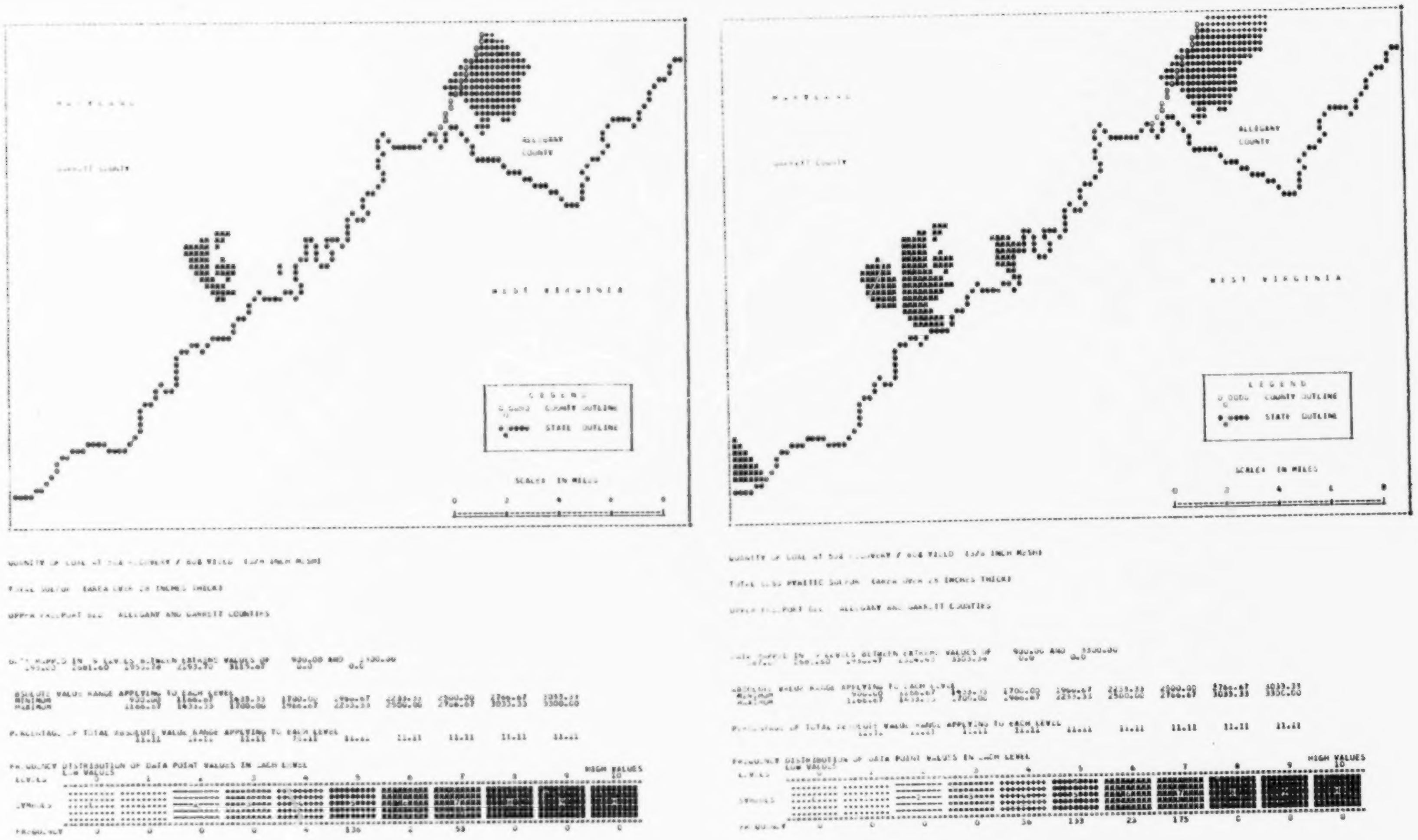


Figure H-5
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal Washed to less than 1% Sulfur
At 80% yield
3/8" mesh; for area over 28" thick
left: total sulfur; right: total less pyrific sulfur

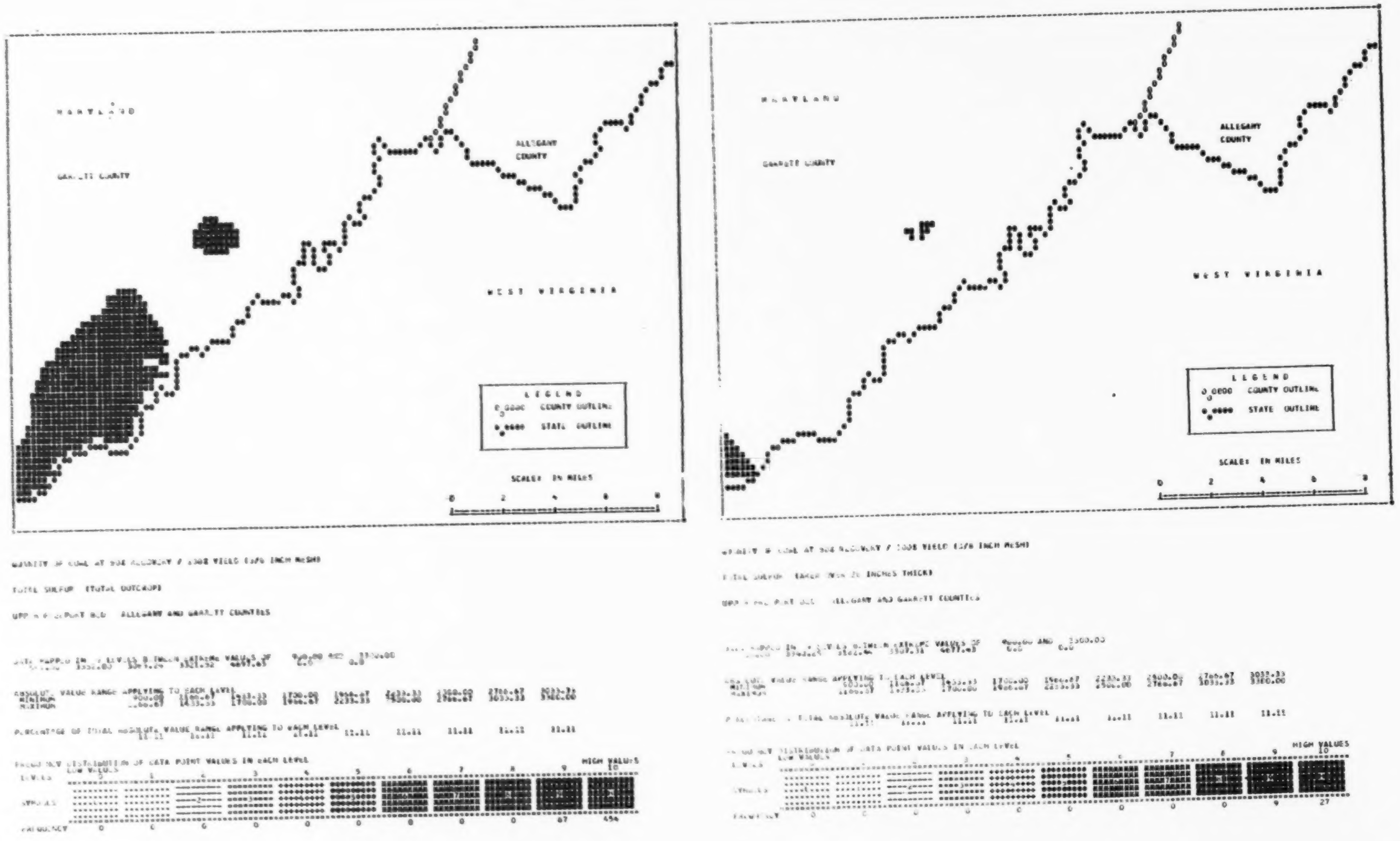


Figure H-6
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal with less than 1% Sulfur
(100% yield, based on Figure F-3)
left: total outcrop; right: area over 28" thick

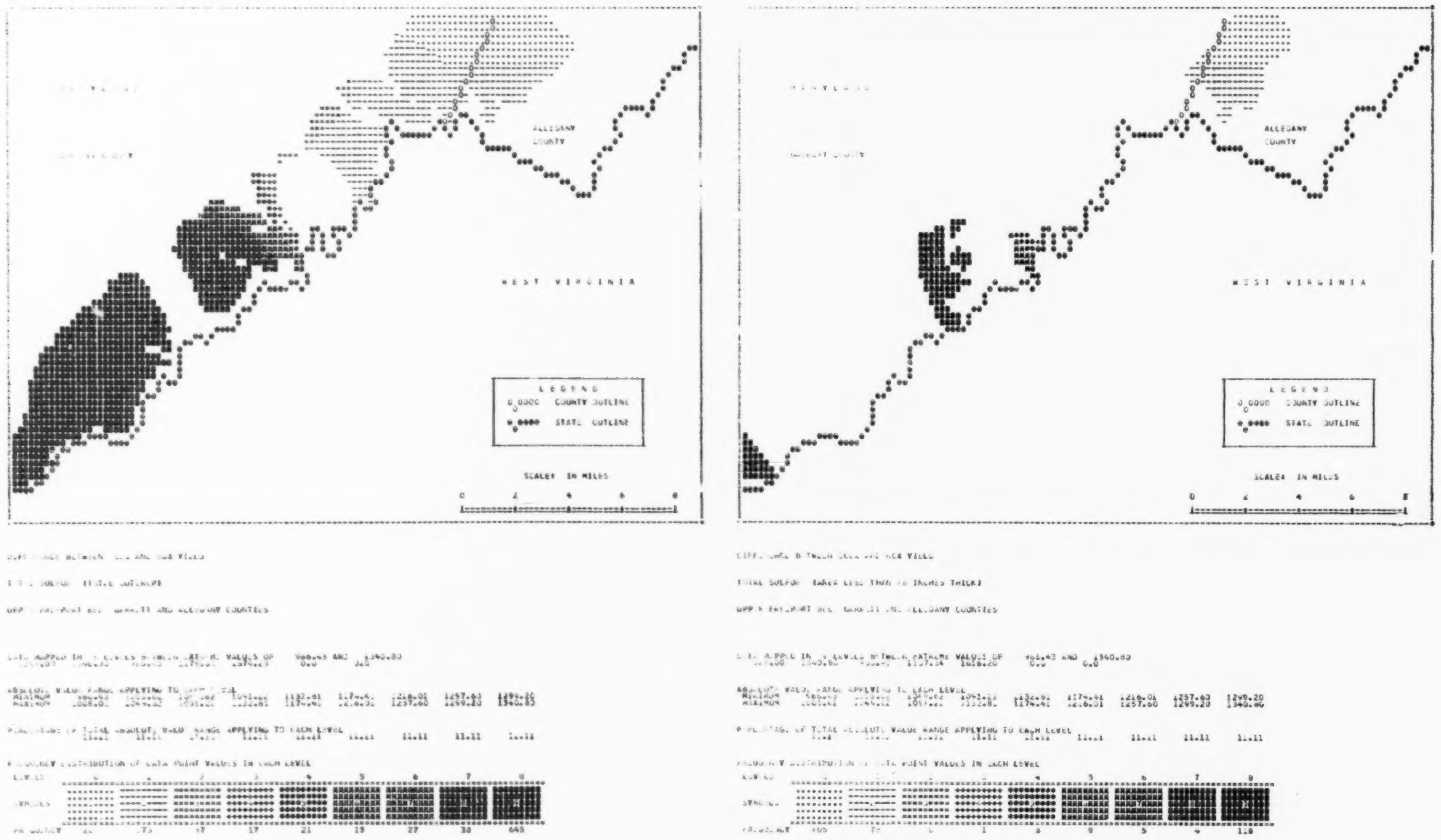


Figure H-7
Center Portion of Allegheny and Garrett Counties
Upper Freeport Coal Bed
Quantity (at 50% recovery) of Coal with less than 1% Sulfur
Difference between 100% and 60% yield
left: total outcrop; right: area over 28" thick
(60% yield based on 3/8" mesh total sulfur)

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. STUDY AREA AND DATA CONSIDERATIONS

As expected, the greatest difficulty encountered in the project was the obtaining of adequate data to work with. Sufficient data to produce meaningful results never were available for the detailed study area of Phase III, although this did not significantly detract from the demonstrations of the applicable techniques.

Examination of the graphics produced in Phases I and II has shown that there is a definite need for: (1) a more equal number of analyses at each sampling location and (2) a more evenly distributed pattern of sampling locations. The latter problem is especially acute in Phase II while the former problem pertains to both phases.

In Phase III it was difficult to draw any statistically sound conclusions. The reliability of the thickness data is very suspect and the spatial interpretation of the washability data limited due to the number of data points; consequently, it is not possible to determine with any accuracy the actual quantity of coal that might be available for this particular study area.

Furthermore, not enough information was known about such parameters as the vertical location of samples in a bed to ensure representative data for mapping. Until sufficient data are available to standardize the samples and remove the effects of parameters other than spatial location, substantive results cannot be obtained, except on a larger-scale basis such as Phases I and II.

The study areas for which the computer mapping techniques were demonstrated were selected after reviewing the available analytical, washability and geological data for several possible areas. The criteria for selecting an area for detailed study included: (1) a "reasonable" and "manageable" number of seams, and (2) "adequate" availability of data for each seam for sulfur content, seam thickness and extent, and washability. Subject to these criteria we wished to pick as extensive an area as practicable so as to be able to develop and test large-scale mapping techniques useful to APCO.

The criterion of a "reasonable" and "manageable" number of seams was merely operational: no additional techniques could be demonstrated by working with 10 or 100 seams than with 2 to 5. We were interested in summing quantity of coal for 2 or more seams and were able to demonstrate the technique with 2 seams for Allegany and Garrett Counties in Phase III, Stage One.

In practice any number of seams could be analyzed, mapped, and summed to form a composite. The constraints are: (i) preparing base maps and data banks for each seam, (ii) having data points 'adequately' spaced for each seam, (iii) having a separate computer storage file for each seam, and (iv) having the additional computer budget to prepare maps for each seam. None of these constraints are significant.

The criterion of "adequate" availability of data for each seam for sulfur content, seam thickness and extent, and washability is harder to define. There is no one magic number--or even range of numbers--that can define the adequacy of data points.

The number of data points necessary for accurate mapping is a function of:

(i) the scale of the map

(ii) the level of detail desired at that scale

(iii) the spacing and clustering of data points, and

(iv) the variability in the surface for the particular variable or phenomenon.

As a minimum, it is difficult to imagine a surface that would be well represented at any scale with fewer than 10 data points* and these 10 should be

a) fairly uniformly spaced

b) non-clustered

c) near the periphery as well as the center of the study area.

If data points are clustered or missing for portions of the study area, additional points should be incorporated to determine a minimum.

The two criteria that are the most changeable are the relationship of the level of detail desired to the scale of the map, and the variability in the surface. If we have a map 10" by 10" and we desire resolution to the nearest inch, then a data point spacing of about 2" should be adequate. The scale of the map is immaterial as long as this ratio of 1" to 10" (or 1:10) is maintained. (Compare Figures B-13 and D-3.)

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*for a procedure to determine the adequacy of data points, see the section on Map Accuracy and Sampling Procedures in Volume Two: General Documentation.

The more variable the surface is for a phenomenon, the greater the number of data points that will be necessary to explain that surface, all else being constant. This can only be determined by statistical measures and sampling for each phenomenon, as discussed in Volume Two: General Documentation.

If we examine our base maps again, the following general conclusions can be made about number of data points and spacing:

1. Phase I (Figures A-1 and A-5) -we cannot infer accuracy below the county level and have large areas of the study area without data points for sulfur content.

2. Phase II (Figures B-1, B-8, B-15, and C-1)--we cannot infer accuracy below the town level, and--relative to the scale and detail--have even larger portions of the study area without data points; Map series C, however, has equal accuracy for all areas mapped because of the use of a maximum search radius about each data point.

3. Phase III - sulfur content (Figures E-1 and E-5)--the data points are not evenly spaced and are clustered; there are virtually no portions of the study areas with adequate data points.

4. Phase III - bed thickness (Figures F-1 and F-2)--the same is true as with the sulfur content data points. Note also that the inadequacy of data points--both the number and the spacing--is compounded when sulfur content and thickness are compared to determine quantity.

5. Phase III - washability (Figure G-1)--there are only five data points; it is not possible to develop a meaningful surface from so few points.

Although the particular study areas may not be representative of the country as a whole, they can adequately demonstrate the scales of analysis useful to APCO. The larger the scale--given the same ratio of detail to scale--the less constraining are the data point requirements, as shown by the Phase I and Phase II maps. But at the scale of one or more counties (Phase III) it is necessary to have good data point coverage by mine location.

As with any contour map, values are exact only at control points. As one moves farther from control points values become less trustworthy. A region with many control points is more likely to have accurate contours than is a region with few control points, all other things being equal. Values at the margin of the map, which are outside the control points are of dubious accuracy. The SYMAP program places all control points on the map so that the reader can have some idea of the likelihood of accuracy.

A final note of caution should be raised concerning the variation in the number of analyses averaged at each data point. Perhaps the best safeguard against making any false inferences is to look at a map in one hand and at the base map which shows the data points and the number of analyses in the other hand. In this way, one is made aware of the number of analyses attributed to a data point and the validity one can infer about any given area of the map.

3.2. MAPPING CONSIDERATIONS

There are several important mapping considerations that have come out of this study, separate from the study area and data considerations. These include:

(i) photographic reproduction,

(ii) graphic symbolism,

(iii) legends for number of analyses, and

(iv) use of composite maps.

Photographic reduction of the maps has certain difficulties. In particular the legends may become illegible and the textual and statistical material printed below the map may lose much of its usefulness. Moreover, the tone discernability of the symbolism is somewhat reduced in almost direct proportion to the amount the maps were photographically reduced. But, it is still felt that a relatively good quality can be attributed to the symbolism.

Some of the problems can be overcome by photographing the legends and explanatory information at another scale. In fact, this was done with the titles shown at the bottom of each page; these were separately photographed and stripped into the negatives before printing. Overlays for certain of the legends can also be used.

The best solution is to experiment at the beginning of a project to determine the optimum combination of study area size, reduction scale, and legend and explanatory information detail to use in the final presentation or publication of the maps. For this project the decisions to map Phase I and Phase II at the scale chosen and to show all legends at the same scale (without overlays) were ultimately responsible for the difficulties in reading some of the maps.

With the exception of class levels, or value range intervals, the map symbolism is the only and, therefore the most important graphic way to portray the meaning of the data. The value of a map may be easily lost or destroyed by a poor choice of symbolism.

In SYMAP this choice of symbolism is usually made by the program; there is a prestored set of symbolism for up to 12 levels. For this project it was felt that this set of symbolism was inadequate because (1) there was not enough differentiation between some of the levels, and (2) the darkness of adjacent levels seemed to be reversed in some cases. Therefore, a unique set of symbolism was devised. Whenever possible this set of symbolism and value range intervals was used.

The numbers of analyses associated with the data points were shown on the base maps as legends to aid the reader. The program which produced these legends can easily be generalized to produce other legends such as mine codes, town names, year samples taken, etc. to be printed on the base maps at or adjacent to the data points. If large scale maps are used or there are few data points, these legends can be used on all maps in a series; because they often obscure the symbolism they are generally used only with base maps.

In Phase III a composite map was made showing the quantity of coal from two different coal seams. This is really only a mapping exercise: because of the difference in elevation separating the two seams, the composite maps produced are of very little value. They assume that the two beds are fairly close together for mining purposes, which, in fact they are not. They also assume that the two beds are similar enough in geologic attributes to be shown together. In producing such composite maps caution must be taken to use surfaces that can meaningfully be combined.

The mapping characteristics of the SYMAP and GRID programs do seem well suited to the displays shown. Overlays of certain legends would probably improve the readability, as would a different scale of photographic reduction. The SYMVU program is useful in conjunction with SYMAP and mainly to visualize the variability in the surfaces.

3.3. APPLICATIONS

The most important application is the mapping of sulfur content and quantity on the same map. Mapping quantity of coal in tons per acre by grid cell may not be the best procedure: quantity is a variable that is better aggregated for areas than displayed spatially as a surface. On the other hand sulfur content and bed thickness are variables that lend themselves well to spatial presentation as surfaces. To show useful information for both sulfur content and quantity at the same time the following procedure might be appropriate:

1) map sulfur content as done in this study

2) map bed thickness as done in this study.

3) critical isolines such as 0.5% or 1.0% could be determined as in this study and a map made showing these for each of the yields.

4) for each area between isolines, such as the area greater than 0.5% but less than 1.0%, the quantity of coal could be calculated based on the varying bed thickness for those areas.

5) these quantities could be printed out below the map or as legends on the map in the appropriate shaded level.

6) the reader can then choose the sulfur content of interest to him and visually see the extent of the area involved and the quantities of coal in all those areas of lesser sulfur content.

7) comparisons can be made between various yields, and screen sizes, with quantities calculated and displayed in a similar manner.

In general for analytical or working purposes, a series of maps could be made with sulfur content or quantity varying for each map and the other variable varying through the series of maps. The recommended procedure would be to produce maps in the series, varying by seam thickness or overburden in intervals. For each interval of seam thickness or overburden sulfur content would be mapped and a number or bar would be printed within each isoline of sulfur level showing the quantity of coal contained therein.

Once the base map is created maps of any number of possibilities and variables may be made inexpensively. The most suggestive may be used. In addition, historical maps of production and reserves may be made, as data over time are accumulated. Some possible maps are:

1) Isopach maps (thickness) by bed and for the total amount of coal underground;

2) Depth of overburden to top of bed(structure contour map); among other things, this will tell us whether strip mining is feasible;

3) Total volume of coal in the ground per acre;

4) Amount of coal recoverable by present methods before treatment per acre;

5) Yield of recoverable coal remaining after treatment per acre for each top size and each bed;

6) Percent sulfur in coal after treatment, (by top size);

7) Net worth of coal in ground by bed after mining and treatment, before shipping--for each size grade and for all size grades;

8) Map of coal sheds about major regions, dependent on transportation costs, and price for each coal grade; and,

9) Dynamic nature of coal sheds as we feed in changes in technology of coal beneficiation, changes in standards of pollution control at the stack, subsidized changes in freight rates, changes in subsidy for expensive technology, and changes in demand if oil or gas is substituted for coal.

Many of the variables mapped can be compared to sulfur content to determine quantity of coal less than a certain percent under varying assumptions. For instance, depth of overburden can be checked at each character cell to be mapped to see if mining is feasible. This can be done using the same procedures as were used to determine quantity for mapping.

It would appear that the best applications can be made at the county and town level as in Phases I and II. It is doubtful that sufficient data can be made available at the mine level in the near future to satisfy the study area and data accuracy criteria.

III. APPENDICES

1. Phases I and II: Appalachian Coal Region
2. Phase III: Allegany and Garrett Counties
3. General References
4. Program Development

1. PHASES I AND II: APPALACHIAN COAL REGION

Phases I and II of the project dealt with a four state area herein called the Appalachian Coal Region. It covered an area approximated by counties containing coal in the Pittsburgh Bed, according to the Bureau of Mines data bank. Phase I was concerned with data on sulfur content for raw and washed samples--aggregated by counties--for the Pittsburgh Bed. Phase II was concerned with data on sulfur content for raw and washed samples--aggregated by towns--for the Pittsburgh Bed and raw samples for the Middle Kittanning Bed.

The following sections describe the work that was done to prepare the data for mapping, including base map preparation, data bank set up and use, and decisions as to the actual running of the maps.

1.1. INPUT TO SYMAP

SYMAP, like any other computer program, is simply a framework in which a user can work. The program provides a variety of options and the programmer merely chooses which ones he wishes to employ in order to create the map.

To produce computer maps, input to the computer in the form of a deck of punched cards must be prepared. This deck will consist of certain introductory cards (job control language and a subroutine) and a number of "packages" each composed of additional cards covering a specific category of information about the map(s) to be produced.

The number of packages used depends, exclusively, on the programmer. In this project a total of 6 packages were set up for SYMAP input:

1. A-OUTLINE--describes the outline of the entire Pittsburgh Coal Bed by specifying the x-y coordinate locations of each significant directional change along that polygon curve. The shape of the bed is thus defined in the program by connecting each vertex to the next to form a series of straight line segments.

2. B-DATA POINTS--describes the point locations to which your data is to be related, by specifying their x-y coordinate locations. These data points may be either the points for which data is available (towns in Phase II), or the centers of areas (counties and/or bed outcrops in counties in Phase I), for which data is available. A printed listing of the data points is found in Table III-1 and III-3 for Phase I and Tables III-5 and III-7 for Phase II.

3. C-LEGENDS--causes certain supplementary information, namely legends, to appear on the face of an output map (e.g., for Phases I and II this meant the graphic scale, legend box, and all the state names) by specifying their coordinate locations and content.

4. C-OTOLEGENDS--describes line legends such as rivers, bridges, roads, and county or state lines which must be adjusted if the size (scale) of the map is altered. Appropriate deletions or additions to these line segments are made in accordance with change in scale. This package adjusts with scale identically to the A-OUTLINE package and with only minor alterations in card order (and not in card format) one package can

easily be converted to the other. In both Phases I and II, the C-OTOLEGENDS package contained the significant state and outside county boundaries of the four-state region.

5. E-VALUES--contains the values or quantitative information applicable to each data point; one value for each data point. It is wisest to label each card for future reference. The order of the cards is not important--any convenient way of arranging them is possible as long as these two packages are in the same order. In Phase I the counties were ordered alphabetically by state and in Phase II alphabetically by state, county, and town. This is the same order in which the data was received. A printed listing of the values is found in Table III-2 and III-4 for Phase I and Tables III-6 and III-8 for Phase II.

6. F-MAP--is the map instruction and execution package. The user specifies an appropriate title to appear below the map as well as electives concerning the size or scale, number of levels, level breaks, map symbolism, minimum and maximum values to be regarded, search radius, etc. A sample F-MAP package is included in Table III-12.

The above brief package descriptions were only intended to present a general discussion of the workings of SYMAP. For a more detailed explanation of the program and its operations, see Volume Two: General Documentation.

1.2. BASE MAP PREPARATION

The first step in producing a computer map is for the user to obtain a source map of the area under study. The map must be prepared in such a form that it is digestable to the computer. It therefore becomes necessary to code a base map that has all the information on it that you wish to show.

For this beginning stage in the project a base map at a scale of 1:250,000 was prepared from the Army Map Service series of the same scale. This particular series was chosen because of the scale, clarity and its availability--the Laboratory has the complete set for the United States. By using this scale, the detail is preserved in reduction and it becomes possible to select portions of the map to blow up for close scrutiny (see maps D-3 thru D-7). These maps also have Universal Transverse Mercator grids (UTM s) marked on the map. This becomes an important factor for Phases II and III since all of the data is located by UTM coordinates.

The entire study area conveniently (and deliberately) rests within one UTM grid zone--zone 17. It was decided that work would be greatly facilitated if the study were to restrict itself to only one UTM zone. This was done because of problems inherent in the projection which make it somewhat difficult to align adjacent UTM zones. Some of the counties were not in zone 17 and were deleted and others were not in the chosen study area. The area was chosen so as to be within the Appalachian Coal Region and contain all of the Pittsburgh bed.

The base map was prepared by tracing 84 conterminous county outlines, in sections, onto the working base map of 69.7" by 77.7" (x-y). Points representing raw and washed data for the Pittsburgh Bed were placed in their respective counties. The coordinates for the outer edge (or outline of the 4 state and county area), the data points, and state lines were all punched in inches and generated by the use of an electronic digitizer.

The use of this machine is imperative in facilitating the work of locating coordinates and eliminates the chance for human error. The digitizer was employed in this project because of its ability to quickly and accurately produce a great number of coordinates in card form. The procedure involved in using this machine is quite simple. The user tapes the base map to the table in such a way that the x and y axes on the map are true to the horizontal and vertical, respectively. The origin is then set by the user to 0, 0 in the top left hand corner of the map. The machine is instructed to measure the coordinates in inches by an interchangable circuit board within the machine. The coordinates are then taken from the map by lining up the cross-hairs on an adjustable arm over the point that one wishes to digitize. By then pressing a button on the arm, the coordinate is taken and transferred to a keypunch which is interfaced to the machine. The keypunch then punches the point in card form giving its x-y coordinates in inches to two decimal places, left-justified to columns 11 and 21 and also punches a unique reference number in columns 73 and 80. The numbers were assigned to these column fields by the use of a drum card in the key punch machine. The resultant card output is in a format compatible to SYMAP input with only minor alterations in terms of the regrouping of cards.

For smaller areas with fewer vertices, this procedure is done by hand with a ruler. The SYMAP program will not accept any outline that has an excess of a hundred vertices in the A-OUTLINE package. Since more than 500 cards were punched in the outline of the conterminous study area, it was necessary to break up the cards into "islands" or sections of 100 vertices or less. In so doing, the appearance of the map is not affected whatsoever. After this procedure was followed, a number of maps were run of the low sulfur Pittsburgh data using different level breaks and symbolism shadings at a scale of 1:633,600 or 1 inch = 10 miles. These maps were run with the study area county outlines as an A-OUTLINE; the remaining work in Phases I and II was done with the bed outcrop as the A-OUTLINE at the same scale.

A 1938 base map at a scale of 1:506,880 or 1 inch = 8 miles, of the Pittsburgh Coal Bed was sent to us by the Bureau of Mines. It was almost exactly half the scale of the base map with which we had been working. However, because of incompatibility of the map projections between our base map at a scale of 1:250,000 and the 1:506,880 map it did not seem feasible at the time to enlarge the map by a factor of two. Therefore the map of the Pittsburgh Coal Bed was enlarged by eye by the similar grid method to fit the 1:250,000 base map. In retrospect, it would have been a lot less time consuming to have photo-enlarged the map anyway, since the error factor would have been so slight in the photo-enlargement and less than enlarging the map by eye. After the outline of the Pittsburgh Bed had been delineated on the base map, it was then digitized and made into 71 different "islands". Each island represents one outcrop or part of an outcrop in the case of the major seams of the Pittsburgh Bed. The time involved in digitizing the base map was three hours. Because of the sensitive and delicate nature of the digitizer, it tends to be prone to errors. These errors, however, are very easily discovered upon running the first base map. From the nearly 2000 cards created, about 200 (or 10%) had validity checks because of a defunct transistor in the machine. This kind of error produces a multiple punch on the card which is unreadable to the computer and therefore unacceptable for processing. This mistake was easily corrected in a matter of a few hours.

The old outline of the study area (the county outline) was then easily converted into the C-OTOLEGENDS package. The state boundaries were also coded as C-OTOLEGENDS in a similar manner. Legends were also made for state names, the graphic scale, and legend box which were input by row and column coordinates taken from the output map. These were all included in the C-LEGENDS package. The C-OTOLEGENDS package was used for all maps in Phase I and II because these legends can adjust in scale. The C-LEGENDS package was changed for the D-series maps.

1.3. PHASE I DATA BANK

A small data bank was sent to us by the Bureau of Mines. The deck consisted of 66 cards for 59 counties in the four state region and is broken down as follows, for the Pittsburgh Bed counties mapped:

# Counties	Raw Data	Washed Data
Maryland	2	0
Ohio	8	3
Pennsylvania	7	5
West Virginia	16	11
	33	19

From the original data bank, the values for the Middle Kittanning Bed were deleted. From the remaining values--for the Pittsburgh Bed--six counties were found to be outside the study area and were deleted: Columbiana, Mahoning, and Stark, Ohio, and Center, Clinton, and Tioga, Pennsylvania. This left the above 33 counties used for mapping. The card format was slightly altered from the original to facilitate the identification of the fields containing values:

Number of Analyses	Columns 1-5
Low Sulfur Value	Columns 6-10
Mode Value	Columns 11-15
High Value	Columns 16-20
Bed Code	Columns 50-52
Raw or Washed	Column 53
Point Sequence Number	Columns 55-56
Three-Digit State Code	Columns 61-63
Three-Digit County Code	Columns 64-66
Two-Digit State Name	Columns 69-70
County Name	Columns 73-80

As was noted in an earlier section, the values and the data points are in a one to one correspondence to each other. Hence, the first value will be associated with the first data point. After all of the values are read into the computer, they are associated with their respective data points and contouring takes place, based on the SYMAP contouring algorithm.

1.4. PHASE I DATA POINT PLACEMENT

There are 33 raw and 19 washed data points in the study area. One data point is assigned to represent an entire

37.87	55.48	PITR 01	190001	MD	ALLEGANY
38.40	54.47	PITR 02	190023	MD	GARRETT
43.50	14.54	PITR 03	340009	OH	ATHENS
31.05	27.86	PITR 04	340013	OH	BELMONT
53.93	10.39	PITR 05	340053	OH	GALLIA
31.15	23.77	PITR 06	340059	OH	GUERNSEY
27.09	27.99	PITR 07	340067	OH	HARRISON
26.38	31.04	PITR 08	340081	OH	JEFFERSO
46.10	13.80	PITR 09	340105	OH	MEIGS
40.04	14.99	PITR 10	340115	OH	MORGAN
25.74	39.93	PITR 11	372003	PA	ALLEGHEN
32.40	45.41	PITR 12	372051	PA	FAYETTE
34.01	37.69	PITR 13	372059	PA	GREENE
20.57	49.61	PITR 14	372063	PA	INDIANA
32.66	54.38	PITR 15	372111	PA	SOMERSET
28.98	37.31	PITR 16	372125	PA	WASHINGT
27.09	46.41	PITR 17	372129	PA	WESTMORE
45.89	39.39	PITR 18	470001	WV	BARBOUR
53.44	29.95	PITR 19	470007	WV	BRAXTON
27.40	33.66	PITR 20	470009	WV	BROOKE
50.33	30.49	PITR 21	470021	WV	GILMER
42.90	35.46	PITR 22	470033	WV	HARRISON
47.11	33.13	PITR 23	470041	WV	LEWIS
39.60	36.45	PITR 24	470049	WV	MARION
34.13	32.36	PITR 25	470051	WV	MARSHALL
49.67	13.73	PITR 26	470053	WV	MASON
42.15	53.00	PITR 27	470057	WV	MINERAL
37.21	38.08	PITR 28	470061	WV	MONGALIA
29.61	33.27	PITR 29	470069	WV	OHIO
42.20	43.04	PITR 30	470077	WV	PRESTON
56.27	16.36	PITR 31	470079	WV	PUTNAM
43.90	39.67	PITR 32	470091	WV	TAYLOR
47.69	38.49	PITR 33	470097	WV	UPSHUR

Key: y and x locations

Table III-1
Phase I Pittsburgh Bed - Raw Data Points

160.	0.7	0.9	1.6	PITR 01	190001	MD	ALLEGANY
1.	0.8	0.8	0.8	PITR 02	190023	MD	GARRETT
11.	3.6	3.6	5.0	PITR 03	340009	OH	ATHENS
322.	2.0	3.8	5.9	PITR 04	340013	OH	BELMONT
7.	1.9	1.9	4.8	PITR 05	340053	OH	GALLIA
7.	4.0	4.8	5.7	PITR 06	340059	OH	GUERNSEY
318.	1.9	3.1	5.5	PITR 07	340067	OH	HARRISON
368.	0.9	2.9	4.9	PITR 08	340081	OH	JEFFERSO
11.	3.0	3.6	5.3	PITR 09	340105	OH	MEIGS
2.	4.5	4.5	4.5	PITR 10	340115	OH	MORGAN
431.	0.7	1.6	4.0	PITR 11	372003	PA	ALLEGHEN
551.	0.5	1.2	3.6	PITR 12	372051	PA	FAYETTE
61.	1.3	2.8	3.5	PITR 13	372059	PA	GREENE
109.	1.1	1.2	2.4	PITR 14	372063	PA	INDIANA
69.	0.7	1.8	2.3	PITR 15	372111	PA	SOMERSET
525.	0.8	2.0	5.0	PITR 16	372125	PA	WASHINGT
552.	0.6	1.1	3.5	PITR 17	372129	PA	WESTMORE
361.	1.7	3.3	5.9	PITR 18	470001	WV	BARBOUR
13.	2.4	2.5	3.2	PITR 19	470007	WV	BRAXTON
44.	1.2	2.5	5.5	PITR 20	470009	WV	BROOKE
106.	1.7	2.3	3.4	PITR 21	470021	WV	GILMER
2448.	1.4	3.1	5.3	PITR 22	470033	WV	HARRISON
89.	2.7	3.3	4.3	PITR 23	470041	WV	LEWIS
404.	0.8	1.6	4.0	PITR 24	470049	WV	MARION
19.	4.2	4.6	5.6	PITR 25	470051	WV	MARSHALL
70.	2.1	2.8	4.1	PITR 26	470053	WV	MASON
1.	0.7	0.7	0.7	PITR 27	470057	WV	MINERAL
1659.	1.5	2.9	4.4	PITR 28	470061	WV	MONGALIA
29.	2.8	3.7	5.0	PITR 29	470069	WV	OHIO
5.	0.9	1.1	1.8	PITR 30	470077	WV	PRESTON
43.	2.3	3.0	3.4	PITR 31	470079	WV	PUTNAM
257.	1.1	2.1	4.4	PITR 32	470091	WV	TAYLOR
12.	2.3	3.1	5.8	PITR 33	470097	WV	UPSHUR

Key: number . low . mode . high

Table III-2
Phase I Pittsburgh Bed - Raw Values

31.05	27.86	PITW 01	340013	OH	BELMONT
27.09	27.99	PITW 02	340067	OH	HARRISON
26.38	31.04	PITW 03	340081	OH	JEFFERSO
25.74	39.93	PITW 04	372003	PA	ALLEGHEN
32.40	45.41	PITW 05	372051	PA	FAYETTE
32.66	54.38	PITW 06	372111	PA	SOMERSET
28.98	37.31	PITW 07	372125	PA	WASHINGT
27.09	46.41	PITW 08	372129	PA	WESTMORE
45.89	39.39	PITW 09	470001	WV	BARBOUR
53.44	29.95	PITW 10	470007	WV	BRAXTON
27.40	33.66	PITW 11	470009	WV	BROOKE
50.33	30.49	PITW 12	470021	WV	GILMER
42.90	35.46	PITW 13	470033	WV	HARRISON
47.11	33.13	PITW 14	470041	WV	LEWIS
39.60	36.45	PITW 15	470049	WV	MARION
34.13	32.36	PITW 16	470051	WV	MARSHALL
49.67	13.73	PITW 17	470053	WV	MASON
37.21	38.08	PITW 18	470061	WV	MONGALIA
29.61	33.27	PITW 19	470069	WV	OHIO

Key: y and x locations

Table III-3
Phase I Pittsburgh Bed - Washed Data Points

406.	2.4	3.8	5.0	PITW 01	340013	OH	BELMONT
117.	1.7	2.5	3.3	PITW 02	340067	OH	HARRISON
65.	1.3	2.7	3.7	PITW 03	340081	OH	JEFFERSO
353.	1.3	1.8	2.6	PITW 04	372003	PA	ALLEGHEN
4.	1.1	1.4	2.6	PITW 05	372051	PA	FAYETTE
3.	1.5	1.5	1.7	PITW 06	372111	PA	SOMERSET
100.	0.9	2.8	4.4	PITW 07	372125	PA	WASHINGT
71.	1.0	1.0	2.7	PITW 08	372129	PA	WESTMORE
245.	1.8	2.5	3.7	PITW 09	470001	WV	BARBOUR
48.	1.0	1.3	2.8	PITW 10	470007	WV	BRAXTON
28.	1.6	1.9	2.7	PITW 11	470009	WV	BROOKE
50.	1.0	1.1	1.8	PITW 12	470021	WV	GILMER
619.	0.9	3.1	5.1	PITW 13	470033	WV	HARRISON
1.	3.0	3.0	3.0	PITW 14	470041	WV	LEWIS
563.	0.7	2.5	3.5	PITW 15	470049	WV	MARION
2.	4.5	4.5	4.7	PITW 16	470051	WV	MARSHALL
29.	2.7	3.3	3.4	PITW 17	470053	WV	MASON
709.	1.7	2.4	3.6	PITW 18	470061	WV	MONGALIA
26.	2.7	3.6	4.5	PITW 19	470069	WV	OHIO

Key: number . low - mode . high

Table III-4
Phase I Pittsburgh Bed - Washed Values

county. As in the case of the outline of the Pittsburgh Bed, the coordinates for the data points were digitized in inches. The rationale for the placement was two-fold:

1. If a map from the Report of Investigation series was available, the point was placed at the center of gravity of the reserves in seams of 28" or more in thickness;

2. If no map existed, then the point was determined by using the center of gravity of the existing Pittsburgh seam for that county based on the 1938 map of 1:506,880 scale.

All vertical coordinates were punched as a decimal number in Columns 11-15 and all horizontal coordinates were punched as a decimal number in Columns 21-25. Columns 50-80 are in the same format as the E-VALUES package. A listing of the data points appears in Table III-1 (raw) and III-3 (washed) and of the values in Table III-2(raw) and III-4 (washed).

1.5. PHASE II DATA BANK

In every respect, except for the number of data points and values, many of the maps created in this phase have the identical SYMAP input format as in the first phase. Some of the maps are blow-ups of certain areas of the region which may merit further study (maps D-3 thru D-7).

An additional coal bed was mapped in Phase II-the Middle Kittanning. There were no base maps available for this bed so contouring was only done within a 5 and 10 mile radius of each town (see maps C-2 thru C-7). It was felt that contouring beyond these limits was perhaps unjustified and therefore misleading. Maps of the Pittsburgh Bed were created in the same way for the purpose of: (1) comparison with the Middle Kittanning Bed and (2) obtaining uniform accuracy over the areas mapped. These maps are in series B-16 thru B-21.

The data as received from the Bureau of Mines were arranged by bed (Pittsburgh followed by Middle Kittanning), alphabetized by state, county, and town, and sequenced by mine number within the towns. This same order was preserved and used in the data bank that was created.

A number of steps were necessary in order to arrive at the appropriate set of values for the Phase II data bank.

The first step concerned removing those towns from the data listing which were not in the 84 county study area. Only towns in the following counties of the Middle Kittanning Bed were deleted: Columbiana, Mahoning, and Stark, Ohio; and Center, Clarion, Clinton, and Tioga, Pennsylvania. In a number of cases, the same town appeared more than once for the same bed. When this occured, the 'town' which had the fewer mines was transfered to the 'town' which had the greater number. These towns for the Pittsburgh Bed were: Hopedale, Ohio, Clarksville, Pennsylvania, Point Marion, Pennsylvania, Burnsville, West Virginia, Worthington, West Virginia; and for the Middle Kittanning bed were: Crooksville, Ohio, New Straitsville, Ohio, Osceola Mills, Pennsylvania, and Philipsburg, Pennsylvania. This procedure was necessary because SYMAP can only associate one value per data point location.

The majority of the towns on the data listing had more than one mine (value) associated with them. As the second step, it was therefore necessary to arrive at one value per town by some sort of a mathematical process. The following procedure was used after advisement by the Bureau of Mines:

Value	Procedure Adopted
Number of Analyses	Mathematically totalled by town
Low Sulfur Value	The lowest sample taken was used for the low value.
Mode Sulfur Value	The most frequent or the mode value was used
High Sulfur Value	The highest of the high values was used.

All addition for the Number of Analyses was checked and rechecked on an adding machine. The low, mode, and high values were verified by eye three separate times for accuracy.

After the non-pertinent towns were deleted and the mine values were totalled by town, the third step involved data analysis. The data was run thru a small statistical computer program called SPSS (Statistical Package for the Social Sciences). This package program, amongst other things, computes the mean, median, mode, variance, standard deviation, skewness, range, minimum and maximum of the data. This kind of information is a most helpful tool to anyone who is making a map because it leads to a better visualization of the data and wiser decisions can be made on how to best display this information.

The SPSS program was used to analyze all the data for Phases I and II. However after meetings with APCO and the Bureau of Mines it was decided to use equal value range intervals for all maps.

As in Phase I, the cards were punched in a set format for easy identification of the fields as follows:

Number of Analyses	Columns 1-5
Low Sulfur Value	Columns 6-10
Mode Value	Columns 11-15
High Value	Columns 16-20
Bed Code	Columns 50-52
Raw or Washed	Column 53
Point Sequence Number	Columns 54-56
Three-Digit State Code	Columns 60-62
Three-Digit County Code	Columns 63-65
Five-Digit Town Code	Columns 66-70
Town Name	Columns 73-80

A card listing for the values of the raw and washed data may be found in Tables III-6 and III-8, respectively, for the Pittsburgh Bed and Table III-10 (raw values) for the Middle Kittanning Bed. The corresponding tables for data point locations are Tables III-5 and III-7 for the Pittsburgh Bed and III-9 for the Middle Kittanning Bed.

1.6. PHASE II DATA POINT PLACEMENT

It was decided to aggregate the mine data to the nearest town. This was done because: (i) many of the mine locations were not yet referenced to the UTM grid, and (ii) such small-scale mapping would create a great number of superimposed data points that would negate the effort expended in doing a map of such detail at the scale selected. Even at the town level, there were 8 superimposed towns occuring at

377.	670.	026R001	19000100800	BARTON
391.	680.	026R002	19000104900	ECKHART
391.	677.	026R003	19000106000	FROSTBUR
381.	673.	026R004	19000109500	LONACONI
384.	675.	026R005	19000110100	MIDLAND
389.	675.	026R006	19000110120	MIDLOTHI
395.	658.	026R007	19002307000	GRANTSVI
361.	417.	026R008	34000901600	AMESVILL
367.	394.	026R009	34000955200	NELSONVI
422.	480.	026R010	34001304180	BAILEY M
426.	485.	026R011	34001304700	BARNESVI
439.	513.	026R012	34001304850	BARTON
430.	521.	026R013	34001305800	BELLAIRE
435.	515.	026R014	34001307970	BLAINE
440.	511.	026R015	34001319480	CRESCENT
441.	505.	026R016	34001325400	FAIRPOIN
444.	494.	026R017	34001326400	FLUSHING
445.	521.	026R018	34001329950	GLEN ROB
445.	488.	026R019	34001335700	HOLLOWAY
440.	498.	026R020	34001339750	LAFFERTY
438.	523.	026R021	34001347800	MARTINS
441.	510.	026R022	34001348730	MAYNARD
430.	515.	026R023	34001355000	NEFFS
412.	516.	026R024	34001367500	POWHATAN
436.	508.	026R025	34001372000	ST. CLAI
424.	521.	026R026	34001374100	SHADYSID
427.	490.	026R027	34001377650	SPEIDEL
311.	403.	026R028	34005315350	CHESHIRE
295.	396.	026R029	34005328100	GALLIPOL
424.	474.	026R030	34005967900	QUAKER C
458.	500.	026R031	34006712100	CADIZ
450.	477.	026R032	34006727500	FREEPORT
472.	504.	026R033	34006729050	GERMANO
463.	508.	026R034	34006735000	HOPEDALE
468.	498.	026R035	34006738300	JEWETT
458.	505.	026R036	34006738920	KENWOOD
448.	483.	026R037	34006765230	PIEDMONT
450.	506.	026R038	34006775350	SHORT CR
457.	506.	026R039	34006782450	UNIONVAL
452.	510.	026R040	34008100600	ADENA
465.	515.	026R041	34008108410	BLOOMING
454.	519.	026R042	34008109350	BRADLEY
457.	531.	026R043	34008110100	BRILLIAN
450.	519.	026R044	34008122200	DILLONVA
484.	529.	026R045	34008124900	EMPIRE
482.	527.	026R046	34008139630	KNOXVILL
462.	533.	026R047	34008152000	MINGO JC
461.	511.	026R048	34008163550	PARLETT
456.	513.	026R049	34008165370	PINEY FO
457.	518.	026R050	34008175900	SMITHFIE
468.	532.	026R051	34008178300	STEUBENV
446.	525.	026R052	34008180800	TILTONSV
478.	533.	026R053	34008181400	TORONTO
469.	525.	026R054	34008190800	WINTERSV
316.	408.	026R055	34010550000	MIDDLEPO
322.	402.	026R056	34010571700	RUTLAND
374.	410.	026R057	34011507940	BISHOPVI
471.	588.	026R058	37200304080	BALDWIN
463.	582.	026R059	37200306520	BETHEL P
455.	601.	026R060	37200307580	BLYTHEDA

Table III-5
Phase II Pittsburgh Bed - Raw Data Points

467.	575.	026R061	37200308800	BRIDGEVI
472.	577.	026R062	37200335800	HEIDELBU
478.	563.	026R063	37200338600	IMPERIAL
477.	577.	026R064	37200338800	INGRAM
460.	582.	026R065	37200344700	LIBRARY
449.	592.	026R066	37200354000	MONONGAH
475.	602.	026R067	37200354150	MONROEVI
477.	574.	026R068	37200354700	MOON RUN
467.	572.	026R069	37200354850	MORGAN
491.	604.	026R070	37200358800	NEW KENS
471.	567.	026R071	37200359900	NOBLESTO
483.	602.	026R072	37200360350	NORTH BE
472.	569.	026R073	37200361600	OAKDALE
453.	601.	026R074	37200377770	SMITHDAL
470.	566.	026R075	37200382150	STURGEON
429.	594.	026R076	37205109700	BROWNSVI
438.	620.	026R077	37205126900	EVERSON
439.	599.	026R078	37205128200	FAYETTE
398.	597.	026R079	37205141740	LAKE LYN
415.	596.	026R080	37205146730	MCCLELLA
406.	593.	026R081	37205149170	MARTIN
411.	594.	026R082	37205149400	MASONTOW
404.	593.	026R083	37205158540	NEW GENE
420.	598.	026R084	37205159300	NEW SALE
428.	632.	026R085	37205159950	NORMALVI
410.	608.	026R086	37205162390	OLIPHANT
419.	609.	026R087	37205162400	OLIVER
398.	594.	026R088	37205166800	POINT MA
406.	601.	026R089	37205177800	SMITHFIE
436.	605.	026R090	37205180900	STAR JCT
417.	608.	026R091	37205186900	UNIONTOW
401.	587.	026R092	37205907600	BOBTOWN
424.	581.	026R093	37205914000	CLARKSVI
400.	592.	026R094	37205919950	DILLINER
420.	580.	026R095	37205949600	MATHER
401.	590.	026R096	37205966850	POLAND M
487.	629.	026R097	37206303800	AVONMORE
487.	637.	026R098	37206313770	CLARKSBU
495.	639.	026R099	37206391200	WEST LEB
420.	674.	026R100	37211106200	BERLIN
414.	666.	026R101	37211131400	GARRETT
408.	669.	026R102	37211150900	MEYERSDA
401.	664.	026R103	37211173300	SALISBUR
459.	545.	026R104	37212503400	AVELLA
441.	584.	026R105	37212506000	BENTLEYV
469.	557.	026R106	37212509980	BULGER
470.	551.	026R107	37212510000	BURGETTS
435.	594.	026R108	37212510400	CALIFORN
456.	568.	026R109	37212510700	CANNONSB
466.	544.	026R110	37212525030	ELDERSVI
428.	585.	026R111	37212530300	FREDERIC
461.	559.	026R112	37212536290	HICKORY
456.	566.	026R113	37212537500	HOUSTON
470.	554.	026R114	37212539970	JOFFRE
469.	565.	026R115	37212546900	MCDONALD
451.	565.	026R116	37212549900	MEADOWLA
468.	559.	026R117	37212551600	MIDWAY
461.	567.	026R118	37212556500	MUSE
441.	594.	026R119	37212580100	SPEERS
463.	565.	026R120	37212587580	VENICE

Table III-5
(Cont'd)

447.	564.	026R121	37212588800	WASHINGT
431.	595.	026R122	37212590000	WEST BRO
463.	614.	026R123	37212900250	ADAMSBUR
463.	627.	026R124	37212907830	BOVARD
469.	616.	026R125	37212913600	CLARIDGE
457.	612.	026R126	37212919070	DARRAGH
465.	644.	026R127	37212919800	DERRY
474.	616.	026R128	37212927200	EXPORT
457.	636.	026R129	37212937470	HOSTETTE
464.	609.	026R130	37212939000	IRWIN
463.	637.	026R131	37212942900	LATROBE
456.	650.	026R132	37212944800	LIGONIER
451.	630.	026R133	37212947830	MAMMOTH
465.	612.	026R134	37212948100	MANOR
472.	633.	026R135	37212957500	NEW ALEX
467.	642.	026R136	37212958150	NEW DERR
455.	631.	026R137	37212966350	PLEASENT
442.	597.	026R138	37212968000	PRICEDAL
460.	607.	026R139	37212970350	RILLTON
439.	620.	026R140	37212974500	SCOTTDAL
479.	625.	026R141	37212977300	SLICKVIL
445.	607.	026R142	37212978000	SMITHTON
452.	627.	026R143	37212986940	UNITED
448.	598.	026R144	37212989410	WEBSTER
460.	653.	026R145	37212994060	WILPEN
450.	610.	026R146	37212995110	WYANO
452.	612.	026R147	37212996600	YUKON
338.	579.	026R148	47000102080	BERRYBUR
341.	573.	026R149	47000103250	BROWNTON
325.	576.	026R150	47000104550	CENTURY
342.	575.	026R151	47000109660	GALLOWAY
333.	583.	026R152	47000121100	PHILIPPI
325.	574.	026R153	47000126840	VOLGA
300.	529.	026R154	47000703600	BURNSVIL
290.	522.	026R155	47000708370	EXCHANGE
468.	538.	026R156	47000905850	COLLIERS
464.	534.	026R157	47000909300	FOLLANSB
460.	540.	026R158	47000926760	VIRGINVI
472.	534.	026R159	47000927300	WEIRTON
458.	533.	026R160	47000927500	WELLSBUR
303.	524.	026R161	47002110080	GILMER
348.	564.	026R162	47003303200	BRIDGEPO
347.	556.	026R163	47003305400	CLARKSBU
358.	550.	026R164	47003306950	DOLA
363.	562.	026R165	47003308280	ENTERPRI
358.	556.	026R166	47003311680	HAYWOOD
353.	557.	026R167	47003312030	HEPZIBAH
334.	556.	026R168	47003315200	LOST CRE
358.	555.	026R169	47003315300	LUMBERPO
355.	558.	026R170	47003317330	MEADOWBR
340.	556.	026R171	47003318600	MOUNT CL
345.	558.	026R172	47003319600	NUTTER F
360.	560.	026R173	47003324300	SHINNSTO
354.	558.	026R174	47003325000	SPELTER
349.	551.	026R175	47003328850	WILSONBU
347.	545.	026R176	47003328980	WOLF SUM
329.	551.	026R177	47004113100	JANE LEW
321.	546.	026R178	47004127900	WESTON
370.	573.	026R179	47004908400	FAIRMONT
373.	564.	026R180	47004908800	FARMINGT

Table III-5
(Cont'd)

378.	570.	026R181	47004910800	GRANT TO
366.	570.	026R182	47004913940	KINGMONT
367.	567.	026R183	47004918000	MONONGAH
374.	560.	026R184	47004922050	RACHEL
376.	575.	026R185	47004923200	RIVESVIL
366.	563.	026R186	47004929100	WORTHING
429.	522.	026R187	47005102000	BENWOOD
418.	522.	026R188	47005118500	MOUNDSVI
314.	408.	026R189	47005327550	WEST COL
364.	661.	026R190	47005724110	SHAW
393.	587.	026R191	47006115960	MAIDSVIL
386.	589.	026R192	47006118400	MORGANTO
389.	584.	026R193	47006120050	OSAGE
441.	525.	026R194	47006927130	WARWOOD
435.	526.	026R195	47006928300	WHEELING
360.	598.	026R196	47007718900	NEWBURG
262.	426.	026R197	47007901290	BANCROFT
345.	575.	026R198	47009109200	FLEMINGT
354.	583.	026R199	47009110600	GRAFTON
345.	572.	026R200	47009123460	ROSEMONT
346.	578.	026R201	47009124380	SIMPSON
349.	577.	026R202	47009125720	WENDEL
315.	567.	026R203	47009703400	BUCKHANN

ey: y and x locations

Table III-5
(Cont'd)

29.	0.8	0.9	1.2	026R001	19000100800	BARTON
3.	0.9	0.9	1.2	026R002	19000104900	ECKHART
2.	1.4	1.4	1.6	026R003	19000106000	FROSTBUR
48.	0.8	0.9	1.0	026R004	19000109500	LONACONI
1.	0.9	0.9	0.9	026R005	19000110100	MIDLAND
3.	1.0	1.0	1.0	026R006	19000110120	MIDLOTHI
1.	0.8	0.8	0.8	026R007	19002307000	GRANTSVI
6.	3.6	3.6	3.8	026R008	34000901600	AVESVILL
2.	4.0	4.0	5.0	026R009	34000955200	NELSONVI
1.	5.2	5.2	5.2	026R010	34001304180	BAILEY M
18.	3.6	3.6	5.7	026R011	34001304700	BARNESVI
2.	4.6	4.6	5.6	026R012	34001304850	BARTON
9.	3.7	3.7	4.5	026R013	34001305800	BELLAIRE
1.	4.4	4.4	4.4	026R014	34001307970	BLAINE
2.	3.6	3.6	4.5	026R015	34001319480	CRESCENT
24.	3.3	3.6	3.9	026R016	34001325400	FAIRPOIN
1.	4.9	4.9	4.9	026R017	34001326400	FLUSHING
1.	3.9	3.9	3.9	026R018	34001329950	GLEN ROB
4.	2.0	4.3	5.3	026R019	34001335700	HOLLOWAY
3.	4.2	4.2	5.2	026R020	34001339750	LAFFERTY
7.	3.6	3.8	4.7	026R021	34001347800	MARTINS
1.	3.0	3.0	3.0	026R022	34001348730	MAYNARD
1.	4.9	4.9	4.9	026R023	34001355000	NEFFS
13.	3.8	3.8	4.9	026R024	34001367500	POWHATAN
1.	5.3	5.3	5.3	026R025	34001372000	ST. CLAI
1.	4.3	4.3	4.3	026R026	34001374100	SHADYSID
1.	4.4	4.4	4.4	026R027	34001377650	SHEIDEL
1.	4.4	4.4	4.4	026R028	34005315350	CHESHIRE
3.	3.6	3.6	4.8	026R029	34005328100	GALLIPOL
3.	4.8	4.8	5.7	026R030	34005967900	QUAKER C
87.	1.9	2.4	4.1	026R031	34006712100	CADIZ
2.	3.8	3.8	3.8	026R032	34006727500	FREEPORT
6.	3.6	3.9	4.3	026R033	34006729050	GERMANO
8.	1.1	3.3	3.5	026R034	34006736000	HOPEDALE
5.	2.8	3.0	4.0	026R035	34006738300	JEWETT
2.	3.5	3.5	5.5	026R036	34006738920	KENWOOD
1.	3.1	3.1	3.1	026R037	34006765230	PIEDMONT
1.	3.6	3.6	3.6	026R038	34006775350	SHORT CR
3.	4.0	4.0	4.6	026R039	34006782450	UNIONVAL
2.	4.0	4.0	4.1	026R040	34008100600	ADENA
19.	1.5	3.3	3.9	026R041	34008108410	BLOOMING
1.	3.0	3.0	3.0	026R042	34008109350	BRADLEY
2.	4.0	4.0	4.0	026R043	34008110100	BRILLIAN
3.	3.6	3.7	4.5	026R044	34008122200	DILLONVA
1.	2.6	2.6	2.6	026R045	34008124900	EMPIRE
1.	4.2	4.2	4.2	026R046	34008139630	KNOXVILL
1.	3.2	3.2	3.2	026R047	34008152000	MINGO JC
3.	1.1	1.1	3.6	026R048	34008163550	PARLETT
16.	2.4	3.0	3.0	026R049	34008165370	PINEY FO
7.	1.0	2.4	3.8	026R050	34008175400	SMITHFIE
2.	3.4	3.4	4.0	026R051	34008178300	STEUBENV
1.	4.9	4.9	4.9	026R052	340081[illegible]	TILTONSV
2.	2.7	2.7	4.1	026R053	34008181400	TORONTO
2.	2.4	2.4	3.3	026R054	34008190800	WINTERSV
2.	3.0	3.0	3.3	026R055	34010550000	MIDDLEPO
2.	3.5	3.5	5.3	026R056	34010571700	RUTLAND
2.	4.5	4.5	4.5	026R057	34011507940	BISHOPVI
2.	1.3	1.3	1.4	026R058	37200304080	BALDWIN
1.	1.3	1.3	1.3	026R059	37200306520	BETHEL P
1.	1.2	1.2	1.2	026R060	37200307580	BLYTHEDA

Table III-6
Phase II Pittsburgh Bed - Raw Values

1.	3.1	3.1	3.1	026R061	37200308800	BRIDGEVI
1.	0.9	0.9	0.9	026R062	37200335800	HEIDELBU
15.	0.7	2.0	3.0	026R063	37200338600	IMPERIAL
1.	2.2	2.2	2.2	026R064	37200338800	INGRAM
2.	1.1	1.1	1.5	026R065	37200344700	LIBRARY
12.	1.0	1.0	1.1	026R066	37200354000	MONONGAH
7.	0.9	0.9	1.0	026R067	37200354150	MONROEVI
1.	2.4	2.4	2.4	026R068	37200354700	MOON RUN
1.	2.1	2.1	2.1	026R069	37200354850	MORGAN
2.	2.7	2.7	3.2	026R070	37200358800	NEW KENS
3.	1.2	1.2	1.4	026R071	37200359900	NOBLESTO
1.	1.5	1.5	1.5	026R072	37200360350	NORTH BE
2.	1.6	1.6	2.1	026R073	37200361600	OAKDALE
2.	0.9	0.9	0.9	026R074	37200377770	SMITHDAL
1.	1.6	1.6	1.6	026R075	37200382150	STURGEON
9.	1.3	1.4	1.4	026R076	37205109700	BROWNSVI
1.	0.7	0.7	0.7	026R077	37205126900	EVERSON
5.	0.9	0.9	1.2	026R078	37205128200	FAYETTE
31.	2.1	3.2	3.6	026R079	37205141740	LAKE LYN
2.	1.9	1.9	2.0	026R080	37205146730	MCCLELLA
1.	2.7	2.7	2.7	026R081	37205149170	MARTIN
3.	0.9	0.9	1.9	026R082	37205149400	MASONTOW
4.	0.9	0.9	2.2	026R083	37205155540	NEW GENE
1.	1.0	1.0	1.0	026R084	37205159300	NEW SALE
7.	1.7	1.7	1.7	026R085	37205159950	NORMALVI
1.	1.3	1.3	1.3	026R086	37205162390	OLIPHANT
4.	1.0	1.0	1.1	026R087	37205162400	OLIVER
14.	2.1	2.1	3.5	026R088	37205166800	POINT MA
106.	0.5	1.2	1.9	026R089	37205177800	SMITHFIE
1.	1.2	1.2	1.2	026R090	37205180900	STAR JCT
126.	0.8	0.9	1.1	026R091	37205186900	UNIONTOW
3.	2.5	2.5	3.5	026R092	37205907600	BOBTOWN
4.	0.9	1.3	1.7	026R093	37205914000	CLARKSVI
4.	2.4	2.5	3.2	026R094	37205919950	DILLINER
1.	1.3	1.3	1.3	026R095	37205949500	MATHER
29.	1.5	3.0	3.3	026R096	37205966850	POLAND M
1.	2.4	2.4	2.4	026R097	37206303800	AVONMORE
7.	1.1	1.1	2.0	026R098	37206313770	CLARKSBU
100.	1.1	1.2	1.6	026R099	37206391200	WEST LEB
33.	1.0	1.8	2.3	026R100	37211106200	BERLIN
2.	1.5	1.5	1.8	026R101	37211131400	GARRETT
31.	0.9	1.9	2.3	026R102	37211150900	MEYERSDA
1.	0.7	0.7	0.7	026R103	37211173300	SALISBUR
9.	1.8	2.8	4.4	026R104	37212503400	AVELLA
3.	1.2	1.2	1.4	026R105	37212506000	BENTLEYV
2.	1.6	1.6	1.6	026R106	37212509980	BULGER
7.	2.0	2.0	4.5	026R107	37212510000	BURGETTS
18.	0.8	0.8	1.3	026R108	37212510400	CALIFORN
1.	2.2	2.2	2.2	026R109	37212510700	CANNONSB
1.	3.5	3.5	3.5	026R110	37212525030	ELDERSVI
3.	1.0	1.0	1.1	026R111	37212530300	FREDERIC
1.	2.4	2.4	2.4	026R112	37212536290	HICKORY
4.	1.4	1.4	1.9	026R113	37212537500	HOUSTON
2.	2.6	2.6	4.5	026R114	37212539970	JOFFRE
1.	3.2	3.2	3.2	026R115	37212546900	MCDONALD
3.	1.5	1.5	1.9	026R116	37212549900	MEADOWLA
1.	1.8	1.8	1.8	026R117	37212551600	MIDWAY
1.	2.0	2.0	2.0	026R118	37212556500	MUSE
5.	1.1	1.1	1.1	026R119	37212580100	SPEERS
2.	2.9	2.9	3.2	026R120	37212587580	VENICE

Table III-6
(Cont'd)

6.	1.9	2.3	2.5	026R121	37212588800	WASHINGT
4.	0.9	0.9	1.2	026R122	37212590000	WEST BRO
1.	2.0	2.0	2.0	026R123	37212900250	ADAMSBUR
3.	1.2	1.2	1.3	026R124	37212907830	BOVARD
3.	0.7	1.7	1.8	026R125	37212913600	CLARIDGE
1.	1.4	1.4	1.4	026R126	37212919070	DARRAGH
2.	2.4	2.4	2.5	026R127	37212919800	DERRY
2.	1.5	1.5	1.7	026R128	37212927200	EXPORT
2.	0.9	0.9	1.3	026R129	37212937470	HOSTETTE
4.	1.8	2.0	2.2	026R130	37212939000	IRWIN
3.	0.9	0.9	0.9	026R131	37212942900	LATROBE
3.	1.0	1.0	1.3	026R132	37212944800	LIGONIER
61.	0.9	0.9	1.5	026R133	37212947830	MAMMOTH
11.	0.7	0.9	1.0	026R134	37212948100	MANOR
4.	0.8	0.8	0.9	026R135	37212957500	NEW ALEX
1.	1.2	1.2	1.2	026R136	37212958150	NEW DERR
63.	0.9	1.0	1.2	026R137	37212966350	PLEASANT
1.	1.0	1.0	1.0	026R138	37212968000	PRICEDAL
3.	0.9	0.9	1.0	026R139	37212970350	RILLTON
6.	1.2	1.2	1.4	026R140	37212974500	SCOTTDAL
19.	0.7	1.2	2.0	026R141	37212977300	SLICKVIL
3.	1.0	1.0	1.2	026R142	37212978000	SMITHTON
1.	1.0	1.0	1.0	026R143	37212986940	UNITED
1.	1.0	1.0	1.0	026R144	37212989410	WEBSTER
3.	1.4	1.5	1.6	026R145	37212994060	WILPEN
30.	1.0	1.0	1.3	026R146	37212995110	WYANO
3.	0.6	0.6	1.3	026R147	37212996600	YUKON
4.	3.2	3.2	3.5	026R148	47000102080	BERRYBUR
28.	1.7	1.8	4.5	026R149	47000103250	BROWNTON
4.	4.0	4.3	4.5	026R150	47000104550	CENTURY
1.	3.0	3.0	3.0	026R151	47000109660	GALLOWAY
14.	2.1	2.2	5.2	026R152	47000121100	PHILIPPI
7.	3.1	3.5	5.4	026R153	47000126840	VOLGA
3.	1.7	2.5	3.0	026R154	47000703600	BURNSVIL
3.	2.7	2.7	2.7	026R155	47000708370	EXCHANGE
1.	3.5	3.5	3.5	026R156	47000905850	COLLIERS
10.	1.2	1.7	3.1	026R157	47000909300	FOLLANSB
1.	1.9	1.9	1.9	026R158	47000926760	VIRGINVI
2.	2.3	2.3	2.7	026R159	47000927300	WEIRTON
5.	1.6	1.6	4.6	026R160	47000927500	WELLSBUR
29.	2.1	2.3	3.4	026R161	47002110080	GILMER
38.	2.1	3.3	4.4	026R162	47003303200	BRIDGEPO
44.	2.5	2.9	4.5	026R163	47003305400	CLARKSBU
30.	3.2	4.0	4.9	026R164	47003306950	DOLA
1.	3.6	3.6	3.6	026R165	47003308280	ENTERPRI
2.	3.7	3.7	3.9	026R166	47003311680	HAYWOOD
5.	3.2	3.3	3.4	026R167	47003312030	HEPZIBAH
9.	3.1	3.8	4.5	026R168	47003315200	LOST CRE
16.	2.2	4.0	4.6	026R169	47003315300	LUMBERPO
135.	1.4	2.4	3.1	026R170	47003317330	MEADOWBR
5.	3.0	3.8	4.1	026R171	47003318600	MOUNT CL
5.	3.2	3.2	4.8	026R172	47003319600	NUTTER F
71.	1.4	2.5	4.2	026R173	47003324300	SHINNSTO
22.	2.9	3.1	3.7	026R174	47003325000	SPELTER
7.	3.1	3.8	4.6	026R175	47003328850	WILSONBU
8.	3.1	3.7	4.0	026R176	47003328980	WOLF SUM
9.	3.2	3.2	4.3	026R177	47004113100	JANE LEW
76.	2.7	3.3	4.0	026R178	47004127900	WESTON
1.	1.5	1.5	1.5	026R179	47004908400	FAIRMONT
6.	1.0	1.4	2.8	026R180	47004908800	FARMINGT

Table III-6
(Cont'd)

112.	1.6	1.6	2.4	026R181	47004910800	GRANT TO
6.	0.9	1.2	3.2	026R182	47004913940	KINGMONT
2.	0.8	0.8	2.8	026R183	47004918000	MONONGAH
15.	1.4	1.4	3.7	026R184	47004922050	RACHEL
8.	0.9	1.8	2.7	026R185	47004923200	RIVESVIL
4.	1.1	2.0	2.9	026R186	47004929100	WORTHING
1.	4.5	4.5	4.5	026R187	47005102000	BENWOOD
5.	4.5	4.6	5.3	026R188	47005118500	MOUNDSVI
4.	2.4	2.4	3.6	026R189	47005327550	WEST [illegible]
1.	0.7	0.7	0.7	026R190	47005724110	SHAW
128.	1.5	2.8	4.4	026R191	47006115960	MAIDSVIL
50.	1.8	2.5	3.4	026R192	47006118400	MORGANTO
3.	2.5	2.5	3.1	026R193	47006120050	OSAGE
4.	2.8	2.8	4.3	026R194	47006927130	WARWOOD
1.	4.4	4.4	4.4	026R195	47006928300	WHEELING
3.	0.9	0.9	1.8	026R196	47007718900	NEWBURG
11.	2.5	2.5	2.6	026R197	47007901290	BANCROFT
15.	1.5	1.6	4.4	026R198	47009109200	FLEMINGT
[illegible]	1.5	1.5	3.7	026R199	47009110600	GRAFTON
[illegible]	1.8	2.3	3.6	026R200	47009123460	ROSEMONT
[illegible]	3.4	3.4	3.6	026R201	47009124380	SIMPSON
[illegible]	1.4	2.5	2.5	026R202	47009125720	WENDEL
[illegible]	3.1	3.1	4.2	026R203	47009703400	BUCKHANN

umber . low . mode . high   Key:

Table III-6
(Cont'd)

430.	521.	026W 01	34001305800	BELLAIRE
435.	515.	026W 02	34001307970	BLAINE
445.	521.	026W 03	34001329950	GLEN ROB
423.	507.	026W 04	34001337560	JACOBSBU
430.	515.	026W 05	34001355000	NEFFS
412.	516.	026W 06	34001367500	POWHATAN
436.	508.	026W 07	34001372000	ST. CLAI
458.	500.	026W 08	34006712100	CADIZ
449.	516.	026W 09	34008122770	DUNGLEN
456.	513.	026W 10	34008165370	PINEY FO
471.	588.	026W 11	37200304080	BALDWIN
466.	571.	026W 12	37200318120	CUDDY
478.	563.	026W 13	37200338600	IMPERIAL
408.	606.	026W 14	37205127500	FAIRCHAN
398.	597.	026W 15	37205141740	LAKE LYN
401.	590.	026W 16	37205966850	POLAND M
420.	674.	026W 17	37211106200	BERLIN
459.	545.	026W 18	37212503400	AVELLA
441.	584.	026W 19	37212506000	BENTLEYV
470.	551.	026W 20	37212510000	BURGETTS
466.	544.	026W 21	37212525030	ELDERSVI
463.	565.	026W 22	37212587580	VENICE
447.	564.	026W 23	37212588800	WASHINGT
477.	647.	026W 24	37212907000	BLAIRSVI
464.	640.	026W 25	37212908350	BRADENVI
467.	627.	026W 26	37212934680	HANNASTO
342.	575.	026W 27	47000109660	GALLOWAY
333.	583.	026W 28	47000121100	PHILIPPI
300.	529.	026W 29	47000703600	BURNSVIL
472.	534.	026W 30	47000927300	WEIRTON
303.	524.	026W 31	47002110080	GILMER
347.	556.	026W 32	47003305400	CLARKSBU
358.	550.	026W 33	47003306950	DOLA
363.	562.	026W 34	47003308280	ENTERPRI
334.	556.	026W 35	47003315200	LOST CRE
358.	555.	026W 36	47003315300	LUMBERPO
359.	563.	026W 37	47003320120	OWINGS
349.	551.	026W 38	47003328850	WILSONBU
321.	546.	026W 39	47004127900	WESTON
373.	564.	026W 40	47004908800	FARMINGT
370.	559.	026W 41	47004909450	FOUR STA
378.	570.	026W 42	47004910800	GRANT TO
367.	567.	026W 43	47004918000	MONONGAH
374.	560.	026W 44	47004922050	RACHEL
376.	575.	026W 45	47004923200	RIVESVIL
366.	563.	026W 46	47004929100	WORTHING
418.	522.	026W 47	47005118500	MOUNDSVI
314.	408.	026W 48	47005327550	WEST COL
380.	581.	026W 49	47006107650	EDNA
379.	580.	026W 50	47006108350	EVERETTV
393.	587.	026W 51	47006115960	MAIDSVIL
386.	589.	026W 52	47006118400	MORGANTO
391.	584.	026W 53	47006121920	PURSGLOV
432.	529.	026W 54	47006908160	ELM GROV
433.	531.	026W 55	47006926300	TRIADELP
346.	575.	026W 56	47009109200	FLEMINGT

Table III-7
Phase II Pittsburgh Bed - Washed Data Points

3.	3.7	3.7	3.9	026W	01	34001305800	BELLAIRE
2.	4.1	4.1	4.1	026W	02	34001307970	BLAINE
2.	3.6	3.6	4.2	026W	03	34001329950	GLEN ROB
3.	4.9	4.9	5.0	026W	04	34001337560	JACOBSBU
2.	4.2	4.2	4.4	026W	05	34001355000	NEFFS
11.	3.8	4.3	4.8	026W	06	34001367500	POWHATAN
2.	4.2	4.2	4.3	026W	07	34001372000	ST. CLAI
2.	2.0	2.0	2.8	026W	08	34006712100	CADIZ
1.	3.2	3.2	3.2	026W	09	34008122770	DUNGLEN
4.	2.0	2.3	3.3	026W	10	34008165370	PINEY FO
1.	1.2	1.2	1.2	026W	11	37200304080	BALDWIN
1.	2.0	2.0	2.0	026W	12	37200318120	CUDDY
1.	1.7	1.7	1.7	026W	13	37200338600	IMPERIAL
2.	1.1	1.1	1.4	026W	14	37205127500	FAIRCHAN
2.	2.5	2.5	2.6	026W	15	37205141740	LAKE LYN
1.	3.0	3.0	3.0	026W	16	37205966850	POLAND M
3.	1.5	1.5	1.7	026W	17	37211106200	BERLIN
3.	1.2	1.2	4.2	026W	18	37212503400	AVELLA
1.	1.0	1.0	1.0	026W	19	37212506000	BENTLEYV
7.	2.9	3.1	3.3	026W	20	37212510000	BURGETTS
1.	3.7	3.7	3.7	026W	21	37212525030	ELDERSVI
2.	2.6	2.6	3.1	026W	22	37212587580	VENICE
1.	1.9	1.9	1.9	026W	23	37212588800	WASHINGT
2.	2.6	2.6	2.7	026W	24	37212907000	BLAIRSVI
1.	2.1	2.1	2.1	026W	25	37212908350	BRADENVI
56.	1.0	1.0	1.2	026W	26	37212934680	HANNASTO
11.	2.8	2.8	3.2	026W	27	47000109660	GALLOWAY
1.	3.2	3.2	3.2	026W	28	47000121100	PHILIPPI
4.	1.2	1.6	2.8	026W	29	47000703600	BURNSVIL
1.	2.7	2.7	2.7	026W	30	47000927300	WEIRTON
1.	1.3	1.3	1.3	026W	31	47002110080	GILMER
20.	2.4	2.5	3.1	026W	32	47003305400	CLARKSBU
12.	3.1	3.6	3.8	026W	33	47003306950	DOLA
1.	2.8	2.8	2.8	026W	34	47003308280	ENTERPRI
2.	3.8	3.8	4.2	026W	35	47003315200	LOST CRE
1.	3.5	3.5	3.5	026W	36	47003315300	LUMBERPO
4.	1.9	2.2	2.6	026W	37	47003320120	OWINGS
1.	3.4	3.4	3.4	026W	38	47003328850	WILSONBU
1.	3.0	3.0	3.0	026W	39	47004127900	WESTON
4.	0.9	1.8	2.6	026W	40	47004908800	FARMINGT
11.	1.5	2.7	3.2	026W	41	47004909450	FOUR STA
1.	2.7	2.7	2.7	026W	42	47004910800	GRANT TO
2.	0.7	0.7	1.4	026W	43	47004918000	MONONGAH
4.	1.6	1.7	2.3	026W	44	47004922050	RACHEL
2.	1.2	1.2	2.4	026W	45	47004923200	RIVESVIL
1.	2.1	2.1	2.1	026W	46	47004929100	WORTHING
1.	4.5	4.5	4.5	026W	47	47005118500	MOUNDSVI
1.	3.3	3.3	3.3	026W	48	47005327550	WEST COL
2.	2.7	2.7	2.7	026W	49	47006107650	EDNA
2.	3.3	3.3	3.6	026W	50	47006108350	EVERETTV
4.	1.8	2.5	2.7	026W	51	47006115960	MAIDSVIL
11.	2.3	2.5	3.3	026W	52	47006118400	MORGANTO
3.	2.1	2.1	2.8	026W	53	47006121920	PURSGLOV
2.	3.3	3.3	4.2	026W	54	47006908160	ELM GROV
3.	3.2	3.2	4.1	026W	55	47006926300	TRIADELP
1.	2.6	2.6	2.6	026W	56	47009109200	FLEMINGT

Table III-8
Phase II Pittsburgh Bed - Washed Values

353.	404.	070R 01	34000903600	ATHENS
359.	390.	070R 02	34000913230	CARBONDA
361.	402.	070R 03	34000915100	CHAUNCEY
372.	406.	070R 04	34000930200	GLOUSTER
369.	405.	070R 05	34000937500	JACKSONV
365.	405.	070R 06	34000951350	MILLFIEL
367.	394.	070R 07	34000955200	NELSONVI
372.	399.	070R 08	34000962100	ORRISTON
494.	469.	070R 09	34001951700	MINERAL
472.	418.	070R 10	34003108150	BLISSFIE
448.	423.	070R 11	34003118300	CONESVIL
457.	427.	070R 12	34003119200	COSHOCTO
464.	437.	070R 13	34003127620	FRESNO
458.	436.	070R 14	34003187600	WEST LAF
361.	374.	070R 15	34007353890	MOUNT EL
374.	399.	070R 16	34007354500	MURRAY C
361.	382.	070R 17	34007378250	STARR
476.	440.	070R 18	34007504400	BALTIC
485.	509.	070R 19	34008107200	BERGHOLZ
468.	532.	070R 20	34008178300	STEUBENV
402.	405.	070R 21	34011519800	CROOKSVI
398.	410.	070R 22	34011521020	DEAVERTO
445.	419.	070R 23	34011900250	ADAMS MI
430.	416.	070R 24	34011929380	GILBERT
441.	434.	070R 25	34011962550	OTSEGO
406.	408.	070R 26	34011970900	ROSEVILL
410.	415.	070R 27	34011978540	STOVERTO
414.	405.	070R 28	34011989360	WHITE CO
421.	415.	070R 29	34011992600	ZANESVIL
391.	394.	070R 30	34012710140	BRISTOL
385.	403.	070R 31	34012718350	CONGO
383.	406.	070R 32	34012718900	CORNING
382.	400.	070R 33	34012734500	HEMLOCK
386.	393.	070R 34	34012745330	MCCUNEVI
399.	403.	070R 35	34012745520	MCLUNEY
390.	402.	070R 36	34012754330	MOXAHALA
396.	396.	070R 37	34012757000	NEW LEXI
381.	393.	070R 38	34012758100	NEW STRA
386.	406.	070R 39	34012768700	RENDVILL
405.	401.	070R 40	34012772850	SALTILLO
384.	395.	070R 41	34012774600	SHAWNEE
406.	388.	070R 42	34012776200	SOMERSET
485.	459.	070R 43	34015722400	DOVER
476.	468.	070R 44	34015750300	MIDVALE
487.	474.	070R 45	34015756450	NEW CUMB
483.	461.	070R 46	34015757700	NEW PHIL
484.	447.	070R 47	34015779100	SUGAR CR
471.	465.	070R 48	34015782000	TUSCARAW
335.	368.	070R 49	34016332400	HAMDEN
517.	548.	070R 50	37200719050	DARLINGT
522.	545.	070R 51	37200726260	ENON VAL
520.	550.	070R 52	37200758500	NEW GALI
487.	720.	070R 53	37201301300	ALTOONA
551.	592.	070R 54	37201907990	BOYERS
522.	593.	070R 55	37201910200	BUTLER
538.	589.	070R 56	37201926650	EUCLID
524.	607.	070R 57	37201928350	FENELTON
530.	572.	070R 58	37201967350	PORTERSV
545.	579.	070R 59	37201977500	SLIPPERY
539.	592.	070R 60	37201992290	WEST SUN

Table III-9

Phase II Middle Kittanning Bed - Raw Data Points

503.	687.	070R 61	37202104300	BARNSHOR
538.	735.	070R 62	37203301250	ALLPORT
523.	723.	070R 63	37203309000	BRISBIN
553.	733.	070R 64	37203330920	FRENCHVI
522.	723.	070R 65	37203337600	HOUTZDAL
555.	742.	070R 66	37203340440	KARTHAUS
541.	738.	070R 67	37203341640	KYLERTOW
546.	691.	070R 68	37203346170	LUTHERSB
522.	716.	070R 69	37203347530	MADERA
536.	733.	070R 70	37203354880	MORRISDA
525.	730.	070R 71	37203362920	OSCEOLA
531.	734.	070R 72	37203365500	PHILIPSB
560.	746.	070R 73	37203366940	POTTERSD
549.	697.	070R 74	37203371150	ROCKTON
549.	721.	070R 75	37203375880	SHAWSVIL
541.	722.	070R 76	37203394630	WOODLAND
576.	693.	070R 77	37204708570	BRANDY C
572.	709.	070R 78	37204789430	WEEDVILL
551.	677.	070R 79	37206569700	REYNOLDS
540.	547.	070R 80	37207324710	EDINBURG
564.	540.	070R 81	37208575500	SHARON
443.	685.	070R 82	37211110300	CAIRNBRO
442.	686.	070R 83	37211111800	CENTRAL
441.	674.	070R 84	37211181700	STOYSTOW
333.	583.	070R 85	47000121100	PHILIPPI
248.	490.	070R 86	47001502420	BICKMORE
369.	613.	070R 87	47007714100	KINGWOOD
297.	583.	070R 88	47008304410	CASSITY
310.	590.	070R 89	47008319550	NORTON
292.	567.	070R 90	47009700450	ALEXANDE

ey: y and x locations

Table III-9
(Cont'd)

1.	1.7	1.7	1.7	070R 01	34000903600	ATHENS
30.	1.4	1.8	2.1	070R 02	34000913230	CARBONDA
8.	0.8	1.0	1.8	070R 03	34000915100	CHAUNCEY
1.	2.2	2.2	2.2	070R 04	34000930200	GLOUSTER
1.	1.0	1.0	1.0	070R 05	34000937500	JACKSONV
1.	1.5	1.5	1.5	070R 06	34000951350	MILLFIEL
8.	1.1	2.9	2.9	070R 07	34000955200	NELSONVI
2.	1.4	1.4	3.2	070R 08	34000962120	ORBISTON
1.	4.8	4.8	4.8	070R 09	34001951700	MINERAL
2.	3.2	3.2	3.9	070R 10	34003108150	BLISSFIE
1.	5.4	5.4	5.4	070R 11	34003118300	CONESVIL
11.	1.1	1.9	4.6	070R 12	34003119200	COSHOCTO
1.	3.0	3.0	3.0	070R 13	34003127620	FRESNO
1.	3.8	3.8	3.8	070R 14	34003187600	WEST LAF
1.	3.6	3.6	3.6	070R 15	34007353890	MOUNT PL
7.	0.6	2.4	2.9	070R 16	34007354500	MURRAY C
2.	2.1	2.1	2.1	070R 17	34007378250	STARR
1.	3.2	3.2	3.2	070R 18	34007504400	BALTIC
1.	2.4	2.4	2.4	070R 19	34008107200	BERGHOLZ
4.	2.6	2.6	3.5	070R 20	34008178300	STEUBENV
[illegible]	2.3	3.8	4.8	070R 21	34011519800	CROOKSVI
1.	3.5	3.5	3.5	070R 22	34011521020	DEAVERTO
3.	2.7	2.7	3.8	070R 23	34011900250	ADAMS MI
4.	3.0	3.0	4.2	070R 24	34011929380	GILBERT
3.	3.9	4.3	4.5	070R 25	34011962550	OTSEGO
5.	4.0	4.4	4.6	070R 26	34011970900	ROSEVILL
3.	4.3	4.3	5.5	070R 27	34011978540	STOVERTO
15.	2.8	2.8	4.7	070R 28	34011989360	WHITE CO
1.	4.0	4.0	4.0	070R 29	34011992600	ZANESVIL
1.	3.3	3.3	3.3	070R 30	34012710140	BRISTOL
4.	0.6	1.0	2.1	070R 31	34012718350	CONGO
1.	4.3	4.3	4.3	070R 32	34012718900	CORNING
13.	1.6	2.0	2.6	070R 33	34012734500	HEMLOCK
29.	2.8	3.7	4.1	070R 34	34012745330	MCCUNEVI
1.	3.1	3.1	3.1	070R 35	34012745520	MCLUNEY
1.	4.4	4.4	4.4	070R 36	34012754330	MOXAHALA
9.	2.5	2.7	5.3	070R 37	34012757000	NEW LEXI
15.	2.2	2.2	2.9	070R 38	34012758100	NEW STRA
2.	2.5	2.5	2.7	070R 39	34012768700	RENDVILL
1.	4.6	4.6	4.6	070R 40	34012772550	SALTILLO
26.	1.0	3.0	4.3	070R 41	34012774600	SHAWNEE
1.	4.2	4.2	4.2	070R 42	34012776200	SOMERSET
2.	3.4	3.4	3.6	070R 43	34015722400	DOVER
1.	5.0	5.0	5.0	070R 44	34015750300	MIDVALE
1.	3.5	3.5	3.5	070R 45	34015756450	NEW CUMB
2.	3.8	3.8	4.1	070R 46	34015757700	NEW PHIL
1.	4.1	4.1	4.1	070R 47	34015779100	SUGAR CR
1.	3.9	3.9	3.9	070R 48	34015782000	TUSCARAW
1.	2.4	2.4	2.4	070R 49	34016332400	HAMDEN
3.	0.6	0.6	4.5	070R 50	37200719050	DARLINGT
1.	1.2	1.2	1.2	070R 51	37200726260	ENON VAL
1.	0.9	0.9	0.9	070R 52	37200758500	NEW GALI
2.	1.8	1.8	3.7	070R 53	37201301300	ALTOONA
2.	0.9	0.9	4.0	070R 54	37201907990	BOYERS
3.	1.3	1.3	3.7	070R 55	37201910200	BUTLER
1.	1.6	1.6	1.6	070R 56	37201925650	EUCLID
2.	3.3	3.3	3.4	070R 57	37201928350	FENELTON
3.	4.1	4.1	6.2	070R 58	37201967350	PORTERSV
2.	3.7	3.7	4.1	070R 59	37201977500	SLIPPERY
1.	3.3	3.3	3.3	070R 60	37201992290	WEST SUN

Table III-10
Phase II Middle Kittanning Bed - Raw Values

```
3.   0.6   0.6   1.6                     070R 61    37202104300   BARNESBO
1.   2.7   2.7   2.7                     070R 62    37203301250   ALLPORT
1.   1.8   1.8   1.8                     070R 63    37203309000   BRISBIN
2.   2.1   2.1   2.5                     070R 64    37203330920   FRENCHVI
1.   1.6   1.6   1.6                     070R 65    37203337600   HOUTZDAL
8.   1.3   2.9   2.9                     070R 66    37203340440   KARTHAUS
2.   0.5   0.5   1.0                     070R 67    37203341640   KYLERTOW
1.   1.6   1.6   1.6                     070R 68    37203346170   LUTHERSB
2.   1.2   1.2   1.8                     070R 69    37203347530   MADERA
1.   3.4   3.4   3.4                     070R 70    37203354880   MORRISDA
6.   2.3   2.3   4.2                     070R 71    37203362920   OSCEOLA
2.   1.8   1.8   1.9                     070R 72    37203365500   PHILIPSB
2.   2.5   2.5   3.2                     070R 73    37203366940   POTTERSD
1.   2.5   2.5   2.5                     070R 74    37203371150   ROCKTON
5.   0.5   0.5   1.8                     070R 75    37203375880   SHAWSVIL
5.   1.1   2.2   4.1                     070R 76    37203394630   WOODLAND
1.   1.8   1.8   1.8                     070R 77    37204708570   BRANDY C
1.   3.9   3.9   3.9                     070R 78    37204789430   WEEDVILL
7.   0.6   0.6   0.7                     070R 79    37206569700   REYNOLDS
2.   2.5   2.5   3.9                     070R 80    37207324710   EDINBURG
1.   1.6   1.6   1.6                     070R 81    37208575500   SHARON
1.   1.0   1.0   1.0                     070R 82    37211110300   CAIRNBRO
1.   2.8   2.8   2.8                     070R 83    37211111800   CENTRAL
1.   1.2   1.2   1.2                     070R 84    37211181700   STOYSTOW
1.   1.5   1.5   1.5                     070R 85    47000121100   PHILIPPI
4.   0.8   0.8   1.1                     070R 86    47001502420   BICKMORE
2.   2.8   2.8   4.8                     070R 87    47007714100   KINGWOOD
3.   2.4   2.4   2.8                     070R 88    47008304410   CASSITY
5.   0.8   1.7   1.7                     070R 89    47008319550   NORTON
1.   0.6   0.6   0.6                     070R 90    47009700450   ALEXANDE
```

umber . low . mode . high   Key:

Table III-10
(Cont'd)

4 locations for the Pittsburgh Bed and 2 at 1 location for the Middle Kittanning Bed. In the case where two data points are so close that they are superimposed then the program associates the mean of the values with that location. The character symbol slash (/) was used to represent this phenomenon on the map.

There are 203 raw and 56 washed data points in the Pittsburgh Bed and 90 raw and 15 washed data points in the Middle Kittanning Bed. Since there was so little washed data available in the latter bed, this information was not mapped.

For mapping it is necessary to locate each town by some kind of an x-y coordinate system. SYMAP will accept any unit of measurement as long as one specifies to the program what measurement system is being used. The program expects coordinates to increase in magnitude in both the horizontal and vertical directions, unlike UTM s which increase in magnitude in the horizontal but decrease in the vertical direction. This incompatibility can be overcome in SUBROUTINE FLEXIN. In READ statement 90 (see Table III-11), the vertical (T(1)) and horizontal (T(2)) UTM coordinates are read in from the cards in the B-DATA POINTS package. The difference between these coordinates and the recorded UTM s at the 0,0 origin (626,322) is then divided by the number of UTM s per linear base map inch. These transformed coordinates are in inches and are now compatible as SYMAP input. The resultant town placement is accurate to within one and a half miles. If the coordinates were read into the program unchanged, then the resultant map would have appeared true in the horizontal but upside down in the vertical direction.

It was decided to use UTM measurements since all the coal data at the Bureau of Mines is located by these units for the United States. Thus the four-state region could also serve as a test area to see how SYMAP could be used for coal data anywhere in the United States.

The procedure for locating the 200 plus towns involved using three different map scales. Before any towns could be located, it was necessary to devise a standardized system for the easy removal of coordinates. To this end, a 10x10 kilometer acetate grid overlay was created.

As many towns as possible were located by this method on the Army Map Service 1:250,000 series. All towns are situated within zone 17 of this series. Approximately one tenth of the towns could not be found because of their small size. It was therefore necessary to use USGS maps of a larger scale--namely the 1:62,500 and 1:24,000 map series. The towns were generally located within a county by using the 1968 Rand McNally Commercial Atlas and Marketing Guide and specifically located by examining large scale quadrant maps of the two aforementioned scales. Points representing the towns were located on the 1:250,000 maps by a combination of two methods: (1) accurate latitude and longitude and (2) visual comparison by identifiable physiographic features for further locational accuracy. The UTM coordinates were then easily removed from the map by using the acetate grid.

All UTM coordinates were read to the nearest one kilometer cell. Decisions had to be made concerning two different types of locational situations: (1) if a town was larger than one UTM cell, then the cell nearest to the central business district was used and (2) if a small town (shown by a dot on the map) fell on either the horizontal or vertical line or both then the cell nearest to a mine symbol was used.

Since all the towns were within one UTM zone it was only necessary to record the last three UTM numbers onto cards. All vertical coordinates were punched as a decimal number in Columns 17-20, and all horizontal coordinates were punched as a decimal number in Columns 27-30. Columns 50-80 are in the same format as the E-VALUES package.

All of the data points were sorted by machine in ascending order by their x and y coordinates as a verification in key punching, and in the locational accuracy of the towns. It is a much simpler task to recheck the town locations on the map quadrangles if they are grouped by UTM s. By sorting on both the x and y column field, one sorted listing provides a cross-check for the other. Since each card has a uniquely associated point sequence number, they may be sorted back into the proper order if dropped or out of sequence. It thus becomes important to have the cards numbered and to have a card sorter at your disposal. There are computer utility programs which give a sorted card listing and do not disturb the card order.

1.7. SUBROUTINE FLEXIN

As previously mentioned in the section INPUT to SYMAP, the input deck consists of a few introductory cards which preceed the various packages. Three of these cards are the skeletal framework of an optional sub-program known as SUBROUTINE FLEXIN. Within this framework of instructions (written in FORTRAN IV computer language) the user, commensurate to his programming ability, has considerable latitude and flexibility in the amount and kind of data he can exact from the computer. Even if no data or program manipulation is desired, SUBROUTINE FLEXIN must be provided in a

```
      SUBROUTINE FLEXIN (IFORM,T,FIRST)
      DIMENSION T(3)
      GO TO (10,20,30,40,50,60,70,80,90),IFORM
   10 READ (5,100) T
  100 FORMAT (F5.0,67X,2A4)
      RETURN
   20 READ (5,200) T
  200 FORMAT (5X,F5.1,62X,2A4)
      RETURN
   30 READ (5,300) T
  300 FORMAT (10X,F5.1,57X,2A4)
      RETURN
   40 READ (5,400) T
  400 FORMAT (15X,F5.1,52X,2A4)
      RETURN
   50 READ (5,500) T
  500 FORMAT (F5.0,67X,2A4)
      RETURN
   60 READ (5,600) T
  600 FORMAT (5X,F5.1,62X,2A4)
      RETURN
   70 READ (5,700) T
  700 FORMAT (10X,F5.1,57X,2A4)
      RETURN
   80 READ (5,800) T
  800 FORMAT (15X,F5.1,52X,2A4)
      RETURN
   90 READ (5,900) T(1),T(2)
  900 FORMAT (10X,2F10.2)
      T(1)=(626.-T(1))/6.37
      T(2)=(T(2)-322.)/6.37
      RETURN
      END
```

Table III-11
Subroutine FLEXIN - Phases I & II

"dummy" form since it is an integral part of the SYMAP deck. Such a "dummy" FLEXIN consists of the following three cards: (1) SUBROUTINE FLEXIN (IFORM, T, FIRST) (2) RETURN (3) END. This simple format tells the computer that there are no special manipulations to take place, e.g., data bank retrieval, map axis rotation, card identification, number incrementation, etc., and for the computer to continue reading and executing the successive cards.

In the case of this project, the instructions required to retrieve the data from the E-VALUES package were placed in this subroutine. The values package is essentially a data bank since each card consists of more data than is applicable for any given map, so the necessary retrieval instructions to obtain the data pertinent to a single map are contained within the SUBROUTINE FLEXIN framework.

A single SUBROUTINE FLEXIN was used in both Phases I and II, a listing of which appears in Table III-11. As may be noted in this table there are nine different READ statements, or one READ statement for each execution. However, in Phase I, only six of these executions were performed by the computer. READ statements 20, 30 and 40 produced maps A-2, A-3, and A-4 and READ statement 60, 70 and 80 produced maps A-6, A-7, and A-8. READ statements 10 and 50 were later made obsolete by a separate subroutine to produce the base maps for the raw and washed data for both phases of the project. READ statement 90 is used to manipulate the UTM coordinates into map inches in Phase II and was discussed in that section under Data Point Placement.

An example of SUBROUTINE FLEXIN will be discussed here as used in Phase I. If one wishes to produce a map of raw sulfur content (low value) then it is necessary to put the number 2 in column 5 and the number 33 in columns 9 and 10 of the second card in the E-VALUES package. This first number, 2, causes the second execution in the SUBROUTINE FLEXIN to take place. The FORMAT statement which follows tells the program which columns to read in order to get the pertinent values to be used in the map and to print the name of the county in Columns 73 through 80. The second number on the card in the E-VALUES package, 33, refers to the number of subsequent cards to be read, i.e., the number of counties on file.

1.8. MAP EXECUTION

The F-MAP package is the instruction and execution package of the SYMAP program. For most of the maps in Phases I and II only changes in the data banks and subroutine instructions and in certain electives of the F-MAP package were required from map to map. In general, maps were run in series of six or more maps at a time. The maps run and the changes from run to run are described below. A sample F-MAP package is shown in Table III-12.

For maps A-2 thru A-4 and A-6 thru A-8 the same electives in the F-MAP package were used, with only the titles being changed. These electives were numbers 1 thru 9 which were used as follows:

Elective Number	Description
Elective 1	Output size--specified to produce maps at a 26" width.
Elective 2	Extreme points--specified in terms of map inches from an origin of 0,0. The vertical dimension of the source map is 77.7 inches and the horizontal dimension is 69.7.

```
F-MAP
         FOUR-STATE COAL REGION
PITTSBURGH BED - RAW SULFUR CONTENT (LOW)
    EXPRESSED AS A PERCENT BY COUNTY
    1                     26.0
    2            0.0       0.0      77.7      69.7
    3             9.
    4            0.5
    5            5.0
    6            0.5       0.5       0.5       0.5       0.5       0.5
                 0.5       0.5       0.5
    7
.-=+*XXHN 123456789  LDH   /
 -=-*-=HZ             X
      =I-             A
       IN             V
    8
    9
99999
```

Table III-12
F-MAP Package

Elective 3	Number of levels--nine for the purposes of contouring.
Elective 4	Value Range Minimum--specified at 0.5; values below this level shown in a unique symbolism.
Elective 5	Value Range Maximum--Specified at 5.0; values above this maximum shown as unique symbolism.
Elective 6	Value Range Intervals--specifies the ranges of each of the class intervals.
Elective 7	Symbolism--user-specified symbolism in 9 separate levels.
Elective 8	Contour Lines--suppresses the appearance of white bands between the levels on the map.
Elective 9	Histogram Bars--suppresses the appearance of a histogram below the map.

For Phase II the same electives in the F-MAP package were used for maps B-2 thru B-4 and B-9 thru B-11. For maps B-5 thru B-7 and B-12 thru B-14 elective 3 was changed to 1 level to show the critical isoline of 0.5% and 1.0% sulfur content; elective 7 was changed accordingly and elective 5 was changed to 1.0.

For maps B-16 thru B-21 and C-2 thru C-7 the same electives as in Phase I were used, with the addition of elective 35 specifying the maximum search radius at either 5 miles (1.340 inches) or 10 miles (2.681 inches). In addition, the outline package was removed and converted to a C-OTOLEGENDS package for maps B-14 thru B-21. No outline existed for the Middle Kittanning Bed.

For maps D-4 thru D-7 the same electives as in Phase I were used, with the exception of elective 2--extreme points of (17.6,27.0) and (48.4,53.0) for D-4 and D-6 and (17.6,40.0) and (33.0,53.0) for D-5 and D-7. For map D-3 elective 1 was 13" and elective 2 had extreme points of (35.9, 47.9) and (45.9, 57.6); otherwise the electives were similar to maps B-2 thru B-4 for the left hand map and B-5 thru B-7 for the right hand map. The boxes in maps D-4 and D-6 showing the portion of the study area to be blown up were put in with a C-OTOLEGENDS package. The same legend was used in the blow ups (maps D-5 and D-7) but the legend was overriden by the map border.

The base maps--Figures A-1, A-5, B-1, B-8, B-15, and C-1--were produced in the same manner as maps A-2, A-6, B-2, B-16, and C-2 with the following exceptions. First of all, different symbolism was employed so that the area outside the study area would be shaded and the data point locations would stand out as black squares. Second, the number of analyses was shown as a C-OTOLEGEND above each data point. These legends were created by a special data handling program.

A newly created subroutine--Subroutine MANIP--was used in conjunction with the user Subroutine FLEXIN to produce maps D-1 and D-2. The maps for the mode value of sulfur content (both raw and washed) by county and by town (maps A-3, A-7, B-3, and B-10) were run and the values for each character cell stored on disk. These values were read in and the two surfaces compared at locations on a grid defined by the user in Subroutine FLEXIN; maps A-3 and B-3 were compared to produce D-1 and A-7 and B-10 to produce D-2. Table III-13 shows the Subroutine FLEXIN used. Read statements 31 and 32 refer to the data points for maps D-1 and D-2 respectively, and READ statement 40 to the values to be mapped. The same

```
      SUBROUTINE FLEXIN (IFORM,T,FIRST)
      DIMENSION T(2)
      LOGICAL FIRST
      GO TO (31,40,32,40),IFORM
   31 CONTINUE
      IF (FIRST) CALL MANIP(5,4,1,12,11,77.7,16.0,0.0,0.0,0)
C**********************************************************************
C*    ARGUMENTS - IGRIDX,IGRIDY,MAPNO,ITP,ITPSKR,XYBASE,XYMAP          *
C*       YOMAP,XOMAP,IBACK.                                            *
C*    IGRIDX = ACROSS, IGRIDY = DOWN GRID SPACING FOR CALCULATING FROM *
C*       MAP ON UNIT 8. 1/2 INCH GRID IS 5 X 4, USE 1 X 1 FOR GRID     *
C*    MAPNO = NUMBER OF OUTPUT MAP USING SUBROUTINE - IF ONLY MAP, 0   *
C*       IF FIRST OR OTHER MAP, 1-8, IF LAST MAP, 9.                   *
C*    ITP = UNIT NUMBER OF OUTPUT MAP, USUALLY 12.                     *
C*    ITPSKR = UNIT NUMBER OF SUBROUTINE SCRATCH TAPE, USUALLY 11.     *
C*    XYBASE = X OR Y DIMENSION OF BASE MAP, IN SOURCE UNITS           *
C*    XYMAP = CORRESPONDING DIMENSION OF MAP ON UNIT 8, IN MAP INCHES  *
C*    YOMAP AND XOMAP = X AND Y DISPLACEMENT OF MAP ON UNIT 8 FROM 0-0 *
C*    IBACK = 0 STANDARD. IF > 0, WILL WRITE OUT BACKGROUND CELLS AS   *
C*       INPUT TO GRID PROGRAM.                                        *
C**********************************************************************
      READ(12) ITEST,T(2),T(1)
      IF(ITEST.EQ.99999) IFORM=99999
      RETURN
   32 CONTINUE
      IF(FIRST) CALL MANIP(5,4,9,12,11,77.7,16.0,0.0,0.0,0)
      READ(12) ITEST,T(2),T(1)
      IF(ITEST.EQ.99999) IFORM=99999
      RETURN
   40 CONTINUE
      IF(FIRST) REWIND 12
      READ(12) ITEST,X,Y,V1,V2
      IF(ITEST.EQ.99999) IFORM=99999
      T(1)= V1-V2
      RETURN
      END
```

Table III-13
FLEXIN for Subroutine MANIP

outline and legends packages were used as in the original maps; the data point and values packages were created internally by the program. The F-MAP package employed different electives for minimum and maximum values, number of levels, value range intervals, and symbolism. The same comparison procedure can be made with the GRID program as discussed in the section on Phase III. However, for maps of this size where the study area outline remains the same, the use of the subroutine in SYMAP requires less programming--only one to two additional cards in Subroutine FLEXIN. This subroutine is described in section 4, Program Development.

2. PHASE III: ALLEGANY AND GARRETT COUNTIES

Phase III of the project dealt with a two county area in Maryland, chosen because of the relatively good data available for sulfur content, bed thickness, and washability characteristics. In Stage One of this phase maps were produced with the SYMAP program showing sulfur content and bed thickness by seam for the Upper Freeport and Upper Bakerstown Beds. Maps of quantity of coal in the ground by seam were made using the GRID program.

In Stage Two maps were produced only for the Upper Freeport Bed. Maps showing the sulfur content to which coal could be washed --using various screen thicknesses for washing-- at certain yields were made with the SYMAP program. The GRID program was used to map the quantity of coal that could be obtained at these yields as well as the difference in sulfur content depending upon the screen size used for washing.

The following sections describe the work that was done to prepare the data for mapping, including base map preparation, data bank set up and use, and decisions as to the actual running of the maps.

2.1. INPUT TO GRID

The GRID program is very similar to the SYMAP program, as far as the user is concerned. Many of the options are exactly the same.

In Phases I and II only the SYMAP program was used; in Phase III both SYMAP and GRID were used. For Phase III six packages were used for SYMAP input as was true in Phases I and II.

1. A-OUTLINE--specified the same as in Phases I and II.

2. B-DATA POINTS--the UTM coordinates for mine or sample location for the data on sulfur content, bed thickness, or washability; specified the same as in Phases I and II.

3. C-LEGENDS--specified the same as in Phases I and II.

4. C-OTOLEGENDS--specified the same as in Phases I and II.

5. E-VALUES--specified the same, in data banks, as in Phases I and II.

6. F-MAP--specified the same as in Phases I and II.

The user subroutine FLEXIN, was used in the same way to read in the appropriate values from the data bank (E-VALUES package) and to transform the coordinates (B-DATA POINTS package) from the UTM system to source map inches.

The corresponding instructions for Phase III with the GRID program were as follows:

1. Outline--the GRID program reads in a rectangular matrix of values created by SYMAP; Subroutine FLEXIN of GRID is used to check each cell to see if it is outside the study area. The user does not need to code any outline package.

1. A-OUTLINE--specified the same as in Phases I and II.

2. B-DATA POINTS--the UTM coordinates for mine or sample location for the data on sulfur content, bed thickness, or washability; specified the same as in Phases I and II.

3. C-LEGENDS--specified the same as in Phases I and II.

4. C-OTOLEGENDS--specified the same as in Phases I and II.

5. E-VALUES--specified the same, in data banks, as in Phases I and II.

6. F-MAP--specified the same as in Phases I and II.

The user subroutine FLEXIN, was used in the same way to read in the appropriate values from the data bank (E-VALUES package) and to transform the coordinates (B-DATA POINTS package) from the UTM system to source map inches.

The corresponding instructions for Phase III with the GRID program were as follows:

1. Outline--the GRID program reads in a rectangular matrix of values created by SYMAP; Subroutine FLEXIN of GRID is used to check each cell to see if it is outside the study area. The user does not need to code any outline package.

2. data points--each cell on the rectangular grid that is inside the study area is a data point. These cells are read in according to a format specified in Subroutine FLEXIN; there is no separate data points package.

3. legends--the same legends that appear on the maps produced with SYMAP are used for the maps produced with GRID. One subroutine was changed in SYMAP so that the legends could be output onto disk; likewise, a subroutine was changed in GRID so that these legends could be read in automatically. No separate legends or 'otolegends' packages were required.

4. Values--the values are read in cell by cell according to the instructions in Subroutine FLEXIN. The matrix values for the maps produced by SYMAP were stored in two data banks, one each for Stage One and Stage Two. In the typical case--calculating quantity of coal--the sulfur content would be read in cell by cell; if a cell were inside the study area and the value for sulfur content was less than 1%, then the bed thickness for that cell would be read in. An algorithm is used to calculate quantity in tons/acre based on the bed thickness; the value for this cell is then returned by the Subroutine to the main program for mapping. If the cell is outside the study area (total outcrop, or greater than 28" thick outlines) or the sulfur content is found to be equal to or greater than 1%, then no value is returned and this cell will be coded with

the symbolism for background; a new outline for the area to be mapped is therefore created by the test for sulfur content. No separate values package is needed.

5. Map package--title cards and electives are coded in the same way as with the SYMAP program; many of the electives are exactly the same.

From the preceeding discussion it should be evident that once the SYMAPs had been generated and the matrices of values stored in data banks, it was necessary to specify only the user subroutine and the MAP package to produce maps using the GRID program.

2.2. BASE MAP PREPARATION

Maps of both Garrett and Allegany counties were obtained from the Maryland Geological Service at a scale of 1 to 62500 or approximately 1" = 1 mile. The map of Garrett County showed more detailed information pertaining to the coal beds than that of Allegany County. The Garrett County map (reprinted 1965 on 1959 base) shows in section and in diagram the relative composition of the various geologic formations. It also shows the outcrop line of each of the coal seams existing in the area, along with symbols keyed to the names of the various beds. This detailed information is lacking on the geological map of Allegany County (1956). It was therefore difficult to define the extent of the outcrop lines for both the Upper Freeport and Upper Bakerstown beds.

A second series of maps at 1" = 2 miles was obtained showing the various outcrops and mineable reserves in the coal seams. This is a series of maps that had been prepared by John T. Boyd & Assoc., Mining Engineers, March 1964. These maps show well-defined outlines for the strip and deep coal reserves, including the deep reserve limit for the Upper Bakerstown and the Upper Freeport seams. They also show the portion of each seam greater than 28" thick.

It was decided to use the Boyd maps as a basis for determining the outlines for the computer maps for the two coal seams under study, since they were more complete. However, the clarity of information at this scale was poor. Accordingly, the Boyd maps were enlarged and the information from them transferred to a composite map at a scale of 1" = 1 mile. In this way information on the Garrett and Allegany County maps (also at 1" = 1 mile) could be used and the scale of the base map would be such that portions could be enlarged without losing detail on the final computer maps.

The enlarging was done using a double grid technique. This process consisted of producing gridded overlays for both the small map (1"=2miles) and the large map (1"= 1 mile). These overlays were directly proportional to the scale differences between these two source maps. Using the horizontal and vertical lines of the grids, the outline was transfered quite easily from one scale to the other. Likewise, information was taken from the larger scale so as to produce composite overlay outlines for the Upper Freeport and Upper Bakerstown Coal seams. Periodic adjustments had to be made so that the information would conform to the general outlines of the county geological maps.

A separate overlay was produced for each of the following:

-- 1. Upper Freeport total outcrop;

-- 2. Upper Freeport area over 28" thick;

-- 3. Upper Bakerstown total outcrop;

-- 4. Upper Bakerstown area over 28" thick.

These four overlays served as the source maps for developing the computer base map outline packages. (Overlays for four or five other beds were produced, but these were discarded because sufficient data was lacking for these beds.)

Each of the contiguous areas representing part of a particular coal seam is known as an island, which must be described in terms of the x-y coordinates that define the boundary. These x-y coordinates can be recorded by using a digitizer as in Phases I and II or by hand. The latter procedure was used here based on the relatively small number of vertices to be recorded.

This procedure involved the use of special graph paper with the x-y coordinates printed along one side and the top. The overlay was placed on top of the graph paper and the coordinates for each point were written on coding forms, proceeding from point to point in a clockwise manner, and repeating the starting point to 'close the outline'. This information is then punched onto IBM cards--one pair of coordinates per card. Each island is a separate deck with the decks for all islands forming the A-OUTLINE package. These packages were prepared for each of the four computer base maps.

Each of the base maps was run and any discrepancies with the source maps were noted and corrected. When the Upper Freeport total outcrop base map was tested together with the data point locations, it was found that the 20 data point locations all fell in the two main islands. No data points existed for the island which was in the upper left hand corner of the study area as well as for the small islands on the westernmost side of the study area. It was felt that any information interpolated from the data points to these islands would be invalid and misleading. Therefore, these islands were removed from the outline package and only the two areas shown in Figure E-1 were used for mapping. For the Upper Bakerstown total outcrop base map the data point locations were reasonably well distributed for all islands; accordingly no islands were removed from the outline package. (See Figure E-5)

The two base maps for the areas over 28" thick were prepared directly from the Boyd source maps and are shown in Figures E-1 and E-5. During the testing of these outlines together with the appropriate data points, it became apparent that the location of data points did not correlate very well with the outline defining the areas 28" and greater in thickness; many of the data points fell outside these outlines. However, all of these areas were included if they had been used for the total outcrop map.

The size of the area for mapping in Stage Two for the Upper Freeport Bed was determined by the location of the values for washability. Most of the data points fell within the center portion of the two-county study area used for Stage One. Therefore, it was decided to map only this center area. This area was defined for mapping by changing Elective 2 in

SYMAP. Figure E-1 shows the relationship of the center area to that of the total two county study area. Figure G-1 shows the base map for the Stage Two area. No changes in the A-OUTLINE packages were necessary to produce base maps at this smaller scale.

Four separate legend packages were developed, two for each stage of the mapping. The C-OTOLEGENDS packages for each stage contained identical information, but the C-LEGENDS packages differed according to the scale of the output map. The information provided in each of the C-OTOLEGENDS packages consisted of the state outline showing the border between Maryland and West Virginia and the county border separating Allegany and Garrett Counties. In the C-LEGENDS packages point legends were used for the names: Maryland, West Virginia, Allegany County, Garrett County; the legend block explaining the symbolism used to delineate county and state outlines; and the graphic scale.

The coordinates of the various outlines were located on the source map in the same manner as for the outline packages. Slight adjustments were made to produce a high quality, single character line defining the state and county boundaries. This was necessitated by the reduction in size from the original scale of the source map to the size of the final computer map; a clustering of symbols occured because of the reduction in size. To eliminate this problem the x-y coordinates for the points to be removed were recorded from the output map; a blank symbol was assigned to each of these points, in effect removing the unwanted symbols. These blank symbols were coded as a part of each of the C-LEGENDS packages, but their effect was to override instructions specified in the C-OTOLEGENDS package. This allowed us to develop a pleasing and graphically consistent legend.

With the exception of these blank symbols the uses of the C-LEGENDS and C-OTOLEGENDS packages were the same as in Phases I and II.

2.3. PHASE III DATA BANKS

For Stage One the data banks included sulfur content for both the Upper Freeport and Upper Bakerstown beds as shown in Tables III-14 and III-16. The values shown are the original data provided to us by the Bureau of Mines. The 20 locations for the Upper Freeport Bed included two taken from the Lower Freeport Bed; all locations for Bakerstown coal were in the Upper Bakerstown Bed. As in Phases I and II information on number of analyses, low, mode, and high values for sulfur content were included in the data bank. Although the number of analyses at a location was as high as 78, it was generally 1; accordingly, only the mode values were mapped.

The data banks and data point locations for bed thickness (Stage One) for both beds are shown in Tables III-15 and III-17, and for washability (Stage Two) for the Upper Freeport bed in Table III-18.

2.4. PHASE III DATA POINT PLACEMENT

All of the data points for both the Upper Freeport and Upper Bakerstown beds and for sulfur content, bed thickness, and washability were provided in terms of UTM coordinates. The coordinates corresponded to mine or sample location, or to the best estimate when the coordinates were not available. Often the estimated location would be the nearest town. A procedure was developed to convert these points from the

```
B-DATA POINTS     X
    1   20
                  3769.     6614.                       071R 01    02301550197
                  3726.     6604.                       071R 02    02301550248
                  3550.     6440.                       071R 03    02304200454
                  3537.     6390.                       071R 04    02306950020
                  3961.     6558.                       071R 05    02307000039
                  3957.     6560.                       071R 06    02307000067
                  3953.     6558.                       071R 07    02307000270
                  3961.     6566.                       071R 08    02307000272
                  3957.     6550.                       071R 09    02307000464
                  3953.     6566.                       071R 10    02307000690
                  3900.     6558.                       071R 11    02308330488
                  3851.     6558.                       071R 12    02308330489
                  3623.     6574.                       071R 13    02308700258
                  3645.     6531.                       071R 14    02308700491
                  3520.     6470.                       071R 15    02310400769
                  3407.     6311.                       071R 16    02313480370
                  3608.     6548.                       071R 17    02314290877
                  3662.     6564.                       071R 18    02315270660
                  3969.     6848.                       074R 19    00100750570
                  3957.     6581.                       074R 20    02307000112
99999
E-VALUES          X
    2   20
   2.  2.0  2.0  2.3                                    071R 01    02301550197
   1.  3.7  3.7  3.7                                    071R 02    02301550248
   1.  0.5  0.5  0.5                                    071R 03    02304200454
   1.  1.1  1.1  1.1                                    071R 04    02306950020
  15.  1.2  1.3  1.5                                    071R 05    02307000039
   1.  0.8  0.8  0.8                                    071R 06    02307000067
  78.  0.9  1.1  1.7                                    071R 07    02307000270
   1.  1.1  1.1  1.1                                    071R 08    02307000272
   1.  2.2  2.2  2.2                                    071R 09    02307000464
   2.  1.0  1.0  1.3                                    071R 10    02307000690
   3.  2.7  2.7  5.8                                    071R 11    02308330488
   1.  3.1  3.1  3.1                                    071R 12    02308330489
   1.  2.5  2.5  2.5                                    071R 13    02308700258
   1.  0.7  0.7  0.7                                    071R 14    02308700491
   1.  0.5  0.5  0.5                                    071R 15    02310400769
  31.  0.7  1.2  2.2                                    071R 16    02313480370
  17.  1.8  1.9  2.4                                    071R 17    02314290877
   1.  2.1  2.1  2.1                                    071R 18    02315270660
   1.  1.4  1.4  1.4                                    074R 19    00100750570
   1.  1.8  1.8  1.8                                    074R 20    02307000112
99999
```

Table III-14
Upper Freeport Bed - Sulfur Content

```
B-DATA POINTS     X
    1     7
                  3707.     6383.                     01
                  3603.     6473.                     02
                  3958.     6580.                     03
                  3649.     6571.                     04
                  3952.     6317.                     05
                  3814.     6345.                     06
                  3620.     6538.                     07
99999
E-VALUES            X
    2     7
                    37.                               01
                    48.                               02
                    30.                               03
                    38.                               04
                    43.                               05
                    40.                               06
                    48.                               07
99999
```

Table III-15
Upper Freeport Bed - Thickness

```
B-DATA POINTS     X
    1     7
                    3961.      6817.                          062R 01    00110700423
                    3961.      6817.                          062R 02    00110700460
                    3819.      6523.                          062R 03    02301450042
                    3558.      6467.                          062R 04    02304200454
                    3579.      6505.                          062R 05    02304200580
                    3880.      6558.                          062R 06    02308330136
                    3869.      6558.                          062R 07    02308330333
99999
E-VALUES           X
   2     7
  1.0   0.6   0.6   0.6                                     1              423
  2.0   1.3   1.3   1.7                                      2              460
  1.0   1.8   1.8   1.8                                      3              042
  1.0   3.7   3.7   3.7                                      4              454
  1.0   0.6   0.6   0.6                                      5              580
  1.0   3.3   3.3   3.3                                      6              136
  1.0   3.3   3.3   3.3                                      7              333
99999
```

Key: Number. low. mode. high

Table III-16
Upper Bakerstown Bed - Sulfur Content

```
B-DATA POINTS     X
    1    16
                 3939.     6856.                    01
                 3960.     6818.                    02
                 3810.     6510.                    03
                 3498.     6368.                    04
                 3633.     6524.                    05
                 3591.     6476.                    06
                 3680.     6567.                    07
                 3591.     6476.                    08
                 3645.     6531.                    09
                 3591.     6476.                    10
                 3742.     6368.                    11
                 3729.     6372.                    12
                 3612.     6566.                    13
                 3794.     6515.                    14
                 3761.     6660.                    15
                 3652.     6570.                    16
99999
E-VALUES          X
    2    16
                   38.                               1
                   37.                              02
                   38.                              03
                   52.                              04
                   35.                              05
                   30.                              06
                   42.                              07
                   48.                              08
                   35.                              09
                   30.                              10
                   48.                              11
                   45.                              12
                   35.                              13
                   18.                              14
                   30.                              15
                   38.                              16
99999
```

Table III-17
Upper Bakerstown Bed - Thickness

```
B-DATA POINTS     X
    1    5
                 3939.      6856.                          01
                 3705.      6652.                          02
                 3603.      6473.                          03
                 3633.      6532.                          04
                 3652.      6570.                          05
E-VALUES          X
    2    5
  60 43939 6856 1400 1200 2.79 1.41 1.49 1.59 1.69  .59  .70  .81  .93
  60 43705 6652 1300 1200 3.67  .76  .76  .75  .78  .16  .16  .16  .20
  60 43603 6473 2750 2600 3.83 1.18 1.24 1.29 1.49  .40  .53  .69  .89
  60 43633 6532 2750 2600 4.25  .60  .60  .61  .62  .05  .07  .08  .10
  60 43652 6570 1970 1938 3.04 1.05 1.10 1.16 1.30  .16  .29  .46  .68
99999
```

```
Key:      y    x                       50   60   70   80   50   60   70   80
                                     (yield) total sulfur  (yield)pyritic sulfur
```

```
B-DATA POINTS     X
    1    5
                 3939.      6856.                          01
                 3705.      6652.                          02
                 3603.      6473.                          03
                 3633.      6532.                          04
                 3652.      6570.                          05
99999
E-VALUES          X
    2    5
  60 43939 6856 1400 1200 2.79 0.00 2.03 2.13 2.19 0.00 1.30 1.40 1.47
  60 43705 6652 1300 1200 3.67 0.74 0.74 0.00 0.83 0.08 0.12 0.00 0.24
  60 43603 6473 2750 2600 3.83 1.15 1.30 0.00 1.72 0.47 0.63 0.00 1.05
  60 43633 6532 2750 2600 4.25 0.64 0.66 0.69 0.00 0.12 0.16 0.19 0.00
  60 43652 6570 1970 1938 3.04 1.00 1.15 0.00 1.57 0.37 0.53 0.00 0.95
99999
```

Table III-18
Upper Freeport Bed - Washability

UTM coordinates to the coordinates of the Phase III output maps. An algorithm similar to the one used in Phase II was used for both Stage One and Stage Two.

A separate B-DATA POINTS package (and corresponding E-VALUES package) was prepared for each computer run. This consisted of a separate card for each data point to be mapped. On each card were punched the UTM coordinates of the point, a reference number, and a code related to the mine or sample location.

For both the Upper Freeport and Upper Bakerstown coal seams there were two superimposed data points for the sulfur content values. For the thickness and washability information, there were no superimposed data points; a superimposed data point corresponding to a top bench value was removed from the washability data bank. Table III-19 shows each of the data banks, the number of data points, and the number of superimposed data points.

Several of the seams that were to have been mapped could not be meaningfully analyzed due to the high number of superimposed data points; the effective number of data points was too few for mapping. The SYMAP program handles superimposed data points by summing and calculating a mean for all values that are located at the same point; thus, a new value is calculated for use in the interpolation procedures. Taking the mean of two values that are themselves modal values based on different numbers of analyses may well skew the results in this case.

DATA BANK	ORIGINAL # DATA POINTS	TOTAL # SUPERIMPOSED	EFFECTIVE # FOR MAPPING
Upper Freeport - Sulfur Content	20	2	19
Upper Freeport - Thickness	7	0	7
Upper Bakerstown - Sulfur Content	7	2	6
Upper Bakerstown - Thickness	16	0	16
Upper Freeport - Washability	5	0	5

Table III-19
Superimposed Data Points

2.5. SUBROUTINE FLEXIN

Subroutine FLEXIN is used as a part of both the SYMAP and GRID programs. FLEXIN was used in the SYMAP program to:

1. read in the data points and convert them from UTM coordinates to source map inches. The algorithms following READ Statement 1 in Table III-20 (a sample SYMAP FLEXIN for Phase III) show the conversion made for both Stage One and Stage Two; and,

2. read in all the values for the variables in the appropriate data bank; these values are written out onto a scratch disk file; for each map in a run, the file is rewound and read and the appropriate variable is returned to the main program for mapping.

This form of FLEXIN was used for maps E-2 thru E-4, E-6 thru E-8, E-9 thru E-11, F-1 and F-2, G-2 thru G-5, and G-8 thru G-10.

FLEXIN was used in the GRID program in a slightly different way. When maps were run with SYMAP the matrices of map values were written out onto a disk to create two data banks--one containing all the SYMAPs for Stage One and the other containing all the SYMAPs for Stage Two. These were stored as real values and the entire data bank read in by Subroutine FLEXIN of GRID. Table III-21 shows the Subroutine for Stage One.

In most cases FLEXIN was used in GRID to read in values for sulfur content and thickness; if the cell were inside

```
      SUBROUTINE FLEXIN(IFORM,T,FIRST)
      DIMENSION T(3),S(4)
      LOGICAL FIRST
      GO TO (1,10,20,30),IFORM
    1 READ (5,900) T(1),T(2)
  900 FORMAT (10X,2F10.2)
      T(1)=(3986.-T(1))/16.0428
      T(2)=(T(2)-6285.)/16.0428
      RETURN
   10 IF(FIRST) REWIND 11
      READ (5,100) S,T(2),T(3)
  100 FORMAT (4F5.0,52X,2A4)
      WRITE (11,101) S,T(2),T(3)
  101 FORMAT (4F5.1,2A4)
      T(1)=S(2)
      RETURN
   20 IF (FIRST) REWIND 11
      READ (11,200) T
  200 FORMAT (10X,F5.1,5X,2A4)
      RETURN
   30 IF (FIRST) REWIND 11
      READ (11,300) T
  300 FORMAT (15X,F5.1,2A4)
      RETURN
      END
```

Table III-20
Subroutine FLEXIN - SYMAP

```
      SUBROUTINE FLEXIN(IFCRM,T,FIRST)
      LOGICAL FIRST
      DIMENSION Z(16),IZ(16)
      EQUIVALENCE(Z(1),IZ(1))
      READ (12) Z
      GO TO (1,2,3,4,5,6),IFCRM
    1 CONTINUE
      IF(Z(2).GE.1.0) GO TO 10
      IF(IZ(7).EQ.25) GO TO 10
      T=1676.0*(Z(7)/12.0)
      RETURN
    2 CONTINUE
      IF(Z(5).GE.1.0) GO TO 10
      IF(IZ(8).EQ.25) GO TO 10
      T=1676.0*(Z(8)/12.0)
      RETURN
    3 CONTINUE
      IF(Z(10).GE.1.0) GO TO 10
      IF(IZ(15).EQ.25) GO TO 10
      T=1676.0*(Z(15)/12.0)
      RETURN
    4 CONTINUE
      IF(Z(13).GE.1.0) GO TO 10
      IF(IZ(16).EQ.25) GO TO 10
      T=1676.0*(Z(16)/12.0)
      RETURN
    5 CONTINUE
      IF(Z(2).GE.1.0.AND.Z(10).GE.1.0) GO TO 10
      IF(IZ(7).EQ.25.AND.IZ(15).EQ.25) GO TO 10
      A=1676.0*(Z(7)/12.0)
      B=1676.0*(Z(15)/12.0)
      T=A+B
      RETURN
    6 CONTINUE
      IF(Z(5).GE.1.0.AND.Z(13).GE.1.0) GO TO 10
      IF(IZ(8).EQ.25.AND.IZ(16).EQ.25) GO TO 10
      A=1676.0*(Z(8)/12.0)
      B=1676.0*(Z(16)/12.0)
      T=A+B
      RETURN
   10 T=-999999.0
      RETURN
      END
```

Table III-21
Subroutine FLEXIN - GRID

the study area and the sulfur content was less than 1%, then a value for quantity would be returned to the main program for mapping. The value would be proportional to the bed thickness and was calculated as follows:

$$Q = 1676.0 \times \frac{T}{12.0} \times M \times Y$$

where: Q = quantity in tons per acre
T = thickness in inches
M = adjustment for recovery:
1.00 for reserves and
0.50 for amount mineable.
Y = yield, varying from 0.50 thru
0.80 for the washability data, and
1.00 for reserves.

Since the scale of the map is known and the area in acres of each grid cell can be determined, only a few statements would need to be added to the Subroutine to calculate the total quantity of coal. This would involve summing the quantity in tons per acre for all cells being mapped and multiplying the sum times the acres per grid cell. An approximate answer can be obtained directly from the printout accompanying the maps. Below the chart showing the symbolism the number of cells is printed for each level. For any level, the number of cells can be multiplied by the average quantity in tons per acre for that level and the number of acres per grid cell. The results can be summed for all levels to give the total quantity of coal. Maps F-3 thru F-5 and H-1 thru H-5 were produced using this type of FLEXIN.

Subroutine FLEXIN was used in GRID in another way. For Maps G-6, G-7, and H-7 values were read in, the check for background cells was made (cells outside the study area), and the difference in values calculated. This is similar to the use of Subroutine MANIP in Phase II.

2.6. MAP EXECUTION

For most of the maps in Phase III only changes in the data banks and subroutine instructions and in certain electives of the F-MAP or MAP package were required from map to map. The decks were set up so that a series of maps could be produced in one run.

Most maps employed the same electives in the F-MAP package for SYMAP and the MAP package for GRID:

Elective	SYMAP	GRID
1.	13"	100 rows by 129 columns for Stage One; 76 rows by 129 columns for Stage Two.
2.	extreme points from source map	IFORM number related to the execution statements in FLEXIN
3.	nine levels	nine levels
4, 5, 6, 7.	same way as Phase I & II	Same way as Phase I & II
8.	same way as Phase I & II	(not used.)

Maps E-2 thru E-4, E-6 thru E-8, E-9 thru E-11, F-1 and F-2, G-2 thru G-5, and G-8 thru G-10 were all run with SYMAP with changes occurring only in electives 4 and 5, and in elective 1 from Stage One to Stage Two. Maps F-3 thru F-5 in Stage One and maps G-6, G-7 and H-1 thru H-7 in Stage Two were run with GRID. Changes occured in electives 2, 4, and 5, and in elective 1 from Stage One to Stage Two.

Maps E-1, E-5, and G-1 were base maps; these were run with special symbolism and used only a 'dummy' subroutine.

2.7. INPUT TO SYMVU

Two three-dimensional views were produced for each of four surfaces using the SYMVU program. These surfaces had been produced by SYMAP and the matrix of values stored on disk files for later use by the GRID program; they are stored and read in by SYMVU in a similar way. No changes were necessary in the present version of the SYMVU program to produce these eight plots.

The user of SYMVU must specify a number of electives, similar in nature to the electives of the F-MAP or MAP packages of SYMAP and GRID. These are all contained on two control cards which follow the title card. Table III-22 shows these three cards for the two views of the surface of thickness for the Upper Freeport Bed for areas over 28" thick (the right hand map in Figure F-1). For example the '100' and '129' at the beginning of card 2 specify the number of rows and columns, respectively, on the matrix of values and, correspondingly, on the SYMAP-produced map. If we examine Figure F-1 we will find that the numbers on the borders show us that there are, indeed, 100 rows and 129 columns. These numbers were specified according to the instructions for electives 2-1 and 2-2, respectively; the other numbers on cards 2 and 3 were specified according to similar instructions in the computer program manual.

The next 31 cards are used to specify the north arrow which is composed of 31 small five-pointed stars. At the present time all legends to be shown on the plot must be punched up separately with a card for each character cell. In Table III-22 the first and second integer (92 and 110, respectively) on card 4 are the row and column locations as they would be measured on the SYMAP-produced map; in this case a new legend was created for SYMVU so these points were not measured from the map in Figure F-1. The integer number, 14, is a code for the five-pointed star symbol.

The last three cards are the title card and two control cards for the second of the two views for this surface. The card deck for the views of the other three surfaces were exactly the same, except for the two title cards, and the elective specifying the file number of the data set.

```
U. FREEPORT BED,THICKNESS OF AREAS >28",GARRETT&ALLEGANY COUNTY,MARYLAND
 100 129        2        0        0                 8   1        0  31   4
  60.    0.    6.        3.                                     .04
         92         110        14
         93         109        14
         93         110        14
         93         111        14
         94         108        14
         94         109        14
         94         110        14
         94         111        14
         94         112        14
         95         107        14
         95         108        14
         95         109        14
         95         110        14
         95         111        14
         95         112        14
         95         113        14
         96         106        14
         96         107        14
         96         108        14
         96         109        14
         96         110        14
         96         111        14
         96         112        14
         96         113        14
         96         114        14
         97         109        14
         97         110        14
         97         111        14
         98         109        14
         98         110        14
         98         111        14
U. FREEPORT BED,THICKNESS OF AREAS >28",GARRETT&ALLEGANY COUNTY,MARYLAND
 100 129        4        1        2                 8   1        3  31   4   1
  45. 309.    6.         2.       28.0                          .04
```

Table III-22
Control Cards for SYMYU

3. GENERAL REFERENCES

3.1. APPALACHIAN COAL REGION REFERENCES

U.S. Bureau of Mines Report of Investigations #_________, "Estimate of Known Recoverable Reserves of Coking Coal in __________________ County"; for the following counties maps for the Pittsburgh Bed were found.

State	County	Report #
MD	Allegany	4970
PA	Allegheny	5003
PA	Fayette	4807
PA	Greene	5143
PA	Indiana	4757
PA	Somerset	4998
PA	Washington	5109
PA	Westmoreland	4803
WV	Brooke	5160
WV	Marion	5267
WV	Marshall	5207
WV	Monogalia	5233
WV	Ohio	5171

Unpublished current data from U.S. Bureau of Mines data banks.

3. 2. ALLEGANY AND GARRETT COUNTY REFERENCES

- Amsden, T.W., 1953, Geologic Map of Garrett County, Maryland Geological Survey. (Reprinted 1965) Scale 1:62,500.

- Anon., 1962, Maryland Coal Reserves, Maryland Bureau of Mines, Westernport, Maryland. Mimeo.

- Anon., 1967, Calendar Year 1967 forty-fifth annual report of the Maryland Bureau of Mines. Westernport, Maryland.

- Anon., 1968, List of Publications of the Maryland Geological Survey, Latrobe Hall, Johns Hopkins University, Baltimore, Maryland 21218.

- Berryhill, H. L. Jr., G. W. Colton, W. de Wilt, Jr., J. E. Johnston, 1965, Geologic Map of Allegany County, U.S. Geological Survey and State of Maryland Dept. of Geology, Mines, and Water Resources. Scale 1:62,500.

- Boyd, J. T. and Associates, 1964, Remaining Coal Reserves of Allegany and Garrett Counties, Maryland, Report issued by the company to the State of Maryland. 27p. plus maps.

- Crentz, W. L., and T. Fraser, 1947, "Preparation Characteristics of Maryland Coals," U.S. Bureau of Mines Technical Paper 701.

- Snyder, N. H., and S. J. Aresco, 1953, "Analyses of Tipple and Delivered Samples of Coal (collected during the fiscal years 1948 to 1950 inclusive)," U.S. Bureau of Mines Bulletin 516.

Toenges, A. L., L. A. Turnbull, L. Williams, H. L. Smith, H. J. O'Donnell, H. M. Cooper, R. F. Abernethy, and K. Waage, 1952, "Investigation of Lower Coal Beds in Georges Creek and North Part of Upper Potomac Basins, Allegany and Garrett Counties, Md.," U.S. Bureau of Mines Technical Paper 725.

Toenges, A. L., et al., 1952, "Castleman Basin, Garrett County, Md.," U.S. Bureau of Mines Bulletin 507.

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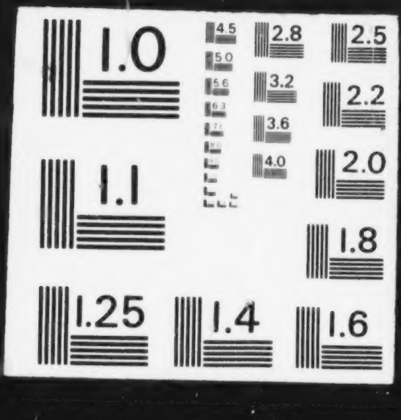

3.3. OTHER REFERENCES

- Beaumont, Edward C., 1963 (August), "A Procedure for Determining Strippable Coal Reserves", reprinted from Coal Age.

- Blaylock, D.W., et al., 1955, "Estimate of Known Recoverable Reserves of Coking Coal in Clearfield County, Pennsylvania." U.S. Bureau of Mines Report of Investigations #5166.

- Crentz, W. L., A. L. Bailey, and J. W. Miller, 1952, "Preparation Characteristics of Coal from Clearfield County, Pa.," U.S. Bureau of Mines Report of Investigations #4894

- DeCarlo, Joseph A., E. T. Sheridan, and Z. E. Murphy, 1966, "Sulfur Content of United States Coals," U.S. Bureau of Mines Information Circular #8312

- Deurbrouck, A. W., and E. R. Palowitch, 1966, "Survey of Sulfur Reduction in Appalachian Region Coals by Stage Crushing," U.S. Bureau of Mines Information Circular 8282.

- Edmunds, Wm. E., 1968, "Geology and Mineral Resources of the Northern Half of the Houtzdale 15-Minute Quadrangle, Pa.," Pennsylvania Geological Survey Bulletin A85ab

- Englund, K. J., 1969, "Availability of Low-Sulfur Coal in Wyoming County, West Virginia," U.S. Geological Survey Administrative Report.

- Gluskoter, Harold J. and J. A. Simon, 1968 "Sulfur in Illinois Coals," Illinois State Geological Survey, Urbana, Illinois

4. PROGRAM DEVELOPMENT

The computer mapping programs as used at the Laboratory for Computer Graphics and Spatial Analysis are constantly undergoing revision and improvement. Accordingly, it is important to specify which version of each program was used for the project:

SYMAP Version 5.15
GRID Version 3
SYMVU Version 1.0.

A number of significant changes in the SYMAP and GRID programs were made during the project to facilitate the mapping of the coal data, particularly data having to do with quantities of coal. In the SYMAP program changes were made in the printout of the textual information below the map. In addition, a new subroutine was written to be used in conjunction with the normal user subroutine for comparing surfaces having the same study area outline. Since the GRID program can generally be used more efficiently for comparison of surfaces, this SYMAP subroutine is only useful for the user who wishes to perform the comparison with one program and one submission.

The major changes to the GRID program involved the rewriting of the legends routine that had been included in previous versions of the program run on the IBM7094. This enables the same kind of legends used with the SYMAP program to be displayed on a map produced by GRID. Formally, it was not possible to include legends with the GRID program. With the inclusion of these changes, the two programs are now completely compatible in terms of graphic output.

The changes made to both the SYMAP and GRID programs were not incorporated into the existing standard versions of the programs. Instead, the specific changes to the standard programs necessary to duplicate the work of this project are documented separately, as requested.

A number of other important changes in the mapping procedure were undertaken as part of the program development; they do not specifically involve changes to the mapping programs. These include:

1. The use of statistical routines incorporated in user-oriented programs to aid in the choosing of the levels or contour intervals for mapping.

2. Data handling procedures used to facilitate the mapping particularly when a large series of maps is involved.

3. The use of a simple FORTRAN program to create legends showing the number of analyses associated with each data point. These legends can be displayed directly on the base map.

Most of the material in the following sections is of a technical nature aimed at the computer programmer interested in using the programs.

4.1. SYMAP PRINT OUT STATEMENTS

Two changes were made in the way that textual information following the maps is printed out by the SYMAP program.

Since the clock subroutine is presently inoperable for runs on the IBM 360-65 at the Harvard Computing Center all statements specifying TIME= were deleted from the printout. Secondly, the way in which the ranges of data values assigned to each of the data value levels has been specified in the past has been unclear to many users of the program. Therefore, the lines stating "absolute value range applying to each level, (maximum included in highest levels only)", were deleted from the printout. The explanation of the value ranges specified which follows this statement was changed as follows:

Value range changed from

level	1.	2.
Minimum	1.00	2.00
Maximum	2.00	3.00 etc.

to

level	1.	2.
Minimum	1.00	2.00
Maximum	1.99	2.99 etc.

In the normal version of the program, it was not clear which level the value 2.00 would be assigned to; in the new printout of the level ranges, this confusion has been eliminated.

The procedure for specifying the portion of the value range to be included in each level in elective 6 remained unchanged; therefore, these minor program modifications have no effect on the way the user inputs his information. They only affect the clarity of his output.

These changes were made only for the Phase I and II Appalachian Coal Region maps; the standard version of SYMAP was used for the Phase III Allegany and Garrett County maps.

4.2. SYMAP SUBROUTINE MANIP

As discussed in later sections of the report, data for sulfur content for the Pittsburgh Bed was mapped in a four state area of the Appalachian Region. In one series of maps the sulfur content data was aggregated and mapped by counties; in a second series of maps, the data was aggregated and mapped by towns. The surfaces resulting from these two data aggregation procedures were compared to determine what scale of aggregation would be most useful, in relation to the time involved in obtaining and manipulating the data.

To compare the two surfaces directly in one submission with the SYMAP program required the writing of a new subroutine entitled Subroutine MANIP. MANIP is called by the normal user subroutine FLEXIN. The parameters to be specified are clearly spelled out in comment statements contained in subroutine FLEXIN; these include the size and form of the surfaces to be compared, the desired size and form of the output map, and the spacing of the grid on which the comparison will be made. Subroutine FLEXIN as used with Subroutine MANIP is shown in Table III-13.

Normally, comparison is not made for each character cell as is done with the GRID program; this is an expense-saving procedure. The use of subroutine MANIP with SYMAP is therefore advisable for comparing large maps where accuracy at each character cell is not necessary. On the other hand, when small maps are being compared and accuracy at each cell is important--as with the determination of the quantity of coal in later phases of the mapping--the use of the GRID program is advisable for surface comparison.

4.3. LEGENDS WITH GRID

Earlier versions of the GRID program--run on the IBM 7094 at the Harvard Computing Center--had provided for a legend package on cards and tape which would allow the inclusion of legends similar to those used with SYMAP. Considerable programming was necessary to make these changes compatible with the current versions of SYMAP and GRID run on the IBM 360-65.

The final solution involved the following changes from the current versions of the programs:

(i) changes in one subroutine of SYMAP so that all legends appearing on the output map are written out by row and column onto a file stored on disk; and,

(ii) changes in one subroutine in GRID so that these legends can be read in by rows and columns and shown on the map output by GRID in the same way they were shown by SYMAP. The maps must be for the same area and at the same size.

For the user the only considerations are using the versions of SYMAP and GRID edited to perform this task. First of all, the special version of SYMAP is used with only the legends and map packages. In the F-MAP package electives 1 and 2 should be specified as usual, elective 3 as one level, and elective 7 with some symbol not used in the legends for both the level and background symbolism. The legends package should be specified as usual. This separate run of SYMAP will create the necessary legends file on disk.

The edited version of the GRID program is used, for mapping. No other changes are necessary from a normal run with the GRID program.

4.4. USE OF STATISTICAL ROUTINES

A user-oriented statistical program called SPSS (Statistical Package for the Social Sciences) was initially used to aid in the choosing of contour intervals for mapping. This package program can compute the mean, median, mode, variance, standard deviation, skewness, range, minimum and maximum of the data. In particular, the user can request a frequency distribution of the data values.

Too often the user of SYMAP does not know the frequency distribution of the data to be mapped; consequently several test maps are made before the optimum value range intervals are determined for the final maps. By using a statistical program such as SPSS to determine the value range intervals, considerable time and money can be saved.

SPSS was used to determine the frequency distribution of all the sulfur content data for Phases I and II. Tentative value range intervals were set accordingly. As a result of review with APCO and the Bureau of Mines, two level breakdowns were selected for use with the Phase I and II maps:

1. nine equal value range intervals from 0.5% to 5.0% sulfur, and

2. critical value level breaks at 0.5% and 1% sulfur; this serves to highlight those areas of the study area with less than 1%, or less than 0.5%, sulfur content coal.

The number of data points available for mapping in Phase III did not warrant the use of SPSS to determine frequency distributions. The same level breakdown was used for sulfur content as in Phases I and II; level breakdowns for bed thickness and quantity were determined by inspection of the data, as were the levels for the washability sulfur content data.

For any project where a large volume of data is to be mapped and several value ranges exist, a program such as SPSS used prior to mapping will prove very useful and time saving.

4.5. DATA HANDLING PROCEDURES

The data handling procedures used for Phases I and II were mainly an extension of prior procedures. Considerable time was spend setting up separate computer decks for each run or series of maps. This was done primarily to keep all of the component packages needed to make specific runs in their proper order. The mapping could have been done by using one basic set of A-OUTLINE, C-OTOLEGEND, and C-LEGEND packages for all runs and interchanging the appropriate B-DATA POINTS, E-VALUES and F-MAP packages. However, experience has shown us that it is worth the extra effort at the beginning of a project to duplicate outline and legend packages and set up separate decks for each series of maps to be run. Otherwise, considerable confusion can occur from constantly switching and alternating the various packages.

When maps for a study area are to be run continuously over a long period of time it would be advisable to store the outline and legends on a tape or disk file, store the data banks of data points and values on other files, and submit card decks for each run which contain only the map package, user subroutine, and job control language.

In Phase I one series of maps run was the sulfur content for washed samples for the Pittsburgh Bed. The deck set-up to produce the three maps for low, mode, and high values was as follows:

1. job control language.

2. user subroutine FLEXIN, used to read in the appropriate values for mapping.

3. outline package.

4. data points package, containing the x-y locations for the washed samples.

5. legends packages.

6. data bank or values packages, containing the data for the low, mode, and high values for each county.

7. map execution packages.

In this case all data were on cards; the deck for the raw samples would differ only for the data points, data bank values, and the title cards of the map packages. Similar procedures were used in Phase II.

In Phase III more sophisticated data handling procedures had to be developed. Considerable thought was given at the outset to the most efficient and logical means for mapping and displaying the information pertaining to this phase of work. Before any mapping was done, the total mapping program was laid out and evaluated. It became apparent that two problems had to be solved in order to produce the required maps efficiently. Both problems are caused by the very inefficient way in which SYMAP is used to take output from one map and use it as input to another:

1. developing a technique to store the output of each computer run; and,
2. developing a technique to retrieve and use this output as input to further computer runs.

For example, the first run might map the mode values for sulfur content and the second run, the thickness of the bed. A third run is then desired to calculate the quantity of coal with less than 1% sulfur content, using the first and second runs. It is necessary to have an efficient technique for storing the matrices of values created by the first two runs and then retrieving them to produce the map in the third run.

Most of the previous work dealing with SYMAP has used tapes as a means of storing output maps. This procedure works quite well when the number of tapes the user is handling is small, but as the number of output tapes increases so does the confusion and difficulty. Consequently, a disk storage device was used to store all of the output maps that were run in Phase III. The procedures involved are almost identical to those used with tapes. Minor modifications were made in the SYMAP program to add the necessary job control language cards and to specify the needed parameters for writing on disks.

The following steps were necessary to set up this procedure:

1. Acquiring a 2314 disk pack from the Harvard Computing Center to be used for storing the basic information. The SYMAP source program was also stored on this disk; although this was not an essential step, it was found to be more efficient to have the mapping program on the same disk, instead of using one disk for data and a separate system disk which normally has SYMAP stored on it.

2. Developing the job control language (JCL) needed for each run. This is a fairly straightforward procedure; these cards specify the disk that is to be mounted, the block size factor, the record format factor, and the space allocation parameters. As SYMAP is currently set up to write its output on channel 8 for tape, this channel was used to write output onto disk. The data file names are specified for each of the output files on the job control cards. These names were carefully selected and organized to eliminate confusion later on in the project.

The GRID program was selected as a second mapping program because of its ability to very efficiently read the previously-stored output files from SYMAP and to manipulate these data to calculate new variables such as quantity. Only slight modifications had to be made in the program for this purpose. It was necessary to write a pre-program that would combine various output files from the SYMAP runs stored on disk into one data bank containing 22 variables.

The standard user subroutine of GRID was then employed to read in specific values from the data bank and manipulate them according to various algorithms developed for this purpose. The results of these calculations were then temporarily stored and graphically portrayed by GRID. For example, a series of maps was run in Stage One of Phase III which displayed the quantity of coal with less than 1% sulfur content. These maps required the use of the GRID program. The user subroutine developed performed the following tasks:

1. Read the matrix of sulfur content values that were stored on a data file on the disk by the SYMAP program;
2. Determine if the value for a particular cell was less than 1%;
3. For those areas where sulfur content was less than 1%, read the thickness data file; also created by the SYMAP program;
4. Calculate the quantity of coal in tons per acre; and,
5. Temporarily store the values for quantity prior to mapping.

Our maps of quantity of coal were displayed in terms of tons per acre. To determine for the particular outcrop or area over 28" thick just how much coal in tons would be available it is necessary to multiply this quantity mapped times the number of acres; the number of acres can be determined by counting up the computer character locations or cells within the study area outline and multiplying by the scale factor for the acreage per character cell. It is possible to write a simple subroutine to do this task within the mapping program. Due to the questionable accuracy of the data used and the quantities determined, as well as the arbitrary study area boundaries chosen, our results were presented only in terms of tons of coal per acre.

4.6. DISPLAYING NUMBER OF ANALYSES ON BASE MAPS

The data banks of sulfur content used in this project generally contained four variables: the low, mode, and high value for sulfur content, and the number of analyses on which these values were based. On the base maps for the study area in Phase I and II the data points, outlines, and legends are displayed, but no values are shown. We wished to display the number of analyses adjacent to each data point to aid in the evaluation of the accuracy of the data for various parts of the study area.

The number of analyses for each data point is displayed on the base map as a point C-OTOLEGEND. A small data handling program was written which performed the following tasks:

1. Read in the data point locations; transform these if the source map units used for data points and legends are different;

2. Read in the corresponding values for the number of analyses at each data point;

3. Punch out cards in the standard C-OTOLEGENDS package when base maps are run.

This program can easily be generalized to produce other legends such as mine codes, town names, year samples taken, etc. to be printed on the base maps at or adjacent to the data points. If large scale maps are used or there are few data points, these legends can be used on all maps in a series; because they often obscure the symbolism they are generally used only with base maps.